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THE SET UP OF PRIMARY CALIBRATION SYSTEM FOR SHOCK ACCELERATION IN NML

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Abstract – This paper mainly describes Taiwan's metrology NML (National Measurement Laboratory) to set up and evaluate a shock accelerometer calibration system which follows the ISO 16063-13:2001 standard. The environmental shock testing of electro-acoustics or electronic spare parts, the product packing falling impact, the automobile collision and the helmet impact test and so on are more and more important for quality and safety. In consideration of that, NML has started to establish the primary shock calibration system which calibrates the accelerometer sensitivity and trace to the metric unit since 2009. The shock machine structure comprises three parts; they are the electromagnetic high-speed hammer, airborne hammer and airborne anvil. The shock machine impact source of primary shock calibration system is excited by electromagnetic method.

The electromagnetic controller inputs a DC voltage to drive electromagnetic high-speed hammer through the DC power source supply. Then the electromagnetic high-speed hammer impacts an airborne hammer, after that, the airborne hammer proceed to impact the PU rubber which is fixed on the end surface of airborne anvil with rigid body motion way. An accelerometer which is mounted on the other end surface of anvil will output the voltage signal during the instantaneous impact. According to different input DC voltage value and different hardness rubber accelerometer will produce different acceleration and duration time. At the same time the accelerometer displacement is measured by combination of modified Michelson and Mach-Zehnder interferometer and acceleration of the accelerometer is derived through two numerical differentiations and two low-pass digital filtering from the displacement.

At present the acceleration capability of primary shock calibration system is from 200 m/s² to 5000 m/s², the shock pulse duration time is less than 3 ms. The final evaluated relative expanded uncertainty is less than 1.0 % within coverage factor $k=1.96$. We shall continue to improve and expand the system acceleration from 100 m/s² to 10000 m/s² for various customers in the future.

Keywords: primary shock calibration system, airborne anvil

1. INTRODUCTION

With the rapid advent of emerging industry, the demands of shock calibration for each kind of electronic and acoustic products, information products, vehicle electronics and precision equipment are increasing. Shock acceleration for major components ranges from 500 m/s² to 5000 m/s².

In addition, the purpose of vehicle shock test is to collect shock force taken by vehicle and passengers as well as related parameters when a vehicle takes place an accident as designing the appropriate bodywork structure and vibration-absorbed device. As it will concern for driver and passenger safety, shock accelerometer used in that test must be calibrated by conscientious trace to ensure all measured data can be correct. According to foreign data, shock acceleration for the driver chest must be less than 588 m/s² when the vehicle speed at 50 km/hr hits the wall. The National Measurement Laboratory has "Shock Calibration System by Comparison Method", which can provide calibration service for industry companies. However, "System Self-trace" can't be provided due to lack of primary calibration system. Standard accelerometer must be delivered to foreign measurement labs for primary calibration. Furthermore, domestic calibration service must be paused 3 to 4 months as well. In view of serving industries and requiring standard self-trace, the NML established the primary calibration system for shock acceleration in 2009.

Physikalisch-Technische Bundesanstalt (PTB) and National Metrology Institute of Japan (NMIJ) have established the calibration system for shock acceleration. PTB produced shock force by compressed mechanical spring; NMIJ used an air pressure hammer to produce external shock force. The primary calibration system for shock acceleration under the NML mainly is established by referring to ISO 16063-13 [1]. The shock source uses electromagnetic excitation, so that an airborne hammer and anvil can produce rigid collision each other. The displacement of accelerometer can be calculated by phase difference 90° interference signals which are collected by modified Michelson and Mach-Zehnder interferometer. The shock acceleration is derived through two numerical

differentiations and two low-pass digital filtering from the displacement value.

This article mainly describes the primary calibration system for shock acceleration structure principle, system evaluation and future development.

2. PRIMARY CALIBRATION SYSTEM FOR SHOCK ACCELERATION

The primary calibration system for shock acceleration is established by referring to ISO 16063-13 rigid body motion method. The system includes Shock Machine, Laser Interferometer and Digital Waveform Recorder. The system photo is as shown in Figure 1.

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 $S_{sh} = \frac{V_{max}}{A_{max}}$ can be determined.

2.1. Shock Machine

The shock source of shock machine (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.

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 this time, 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.

An airborne hammer and anvil in this machine are supported by two radial porous air bushings. 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 accelerometer to install on the back end of an airborne anvil (Figure 3) and measure the lateral motion ratio, which is defined

as $\frac{\sqrt{(A_x^2 + A_y^2)}}{A_z}$. The ratio of maximum lateral motion for that system is less than 4 %.

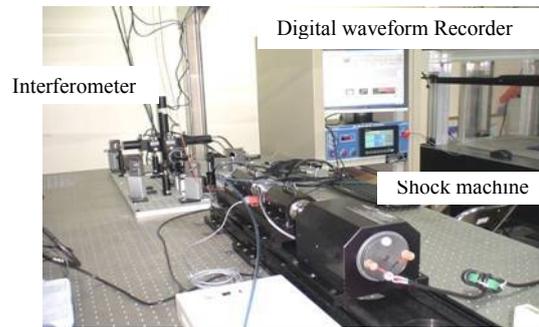


Figure 1 System photo

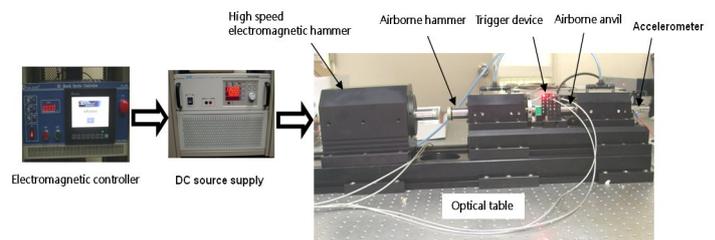


Figure 2 Shock machine modules

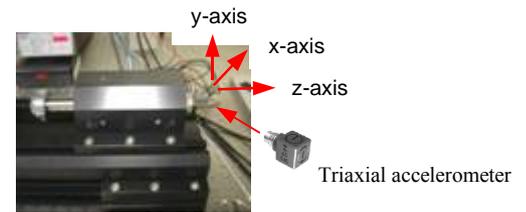


Figure 3 Measurement of lateral motion for triaxial accelerometer

On the other hand, the shock acceleration, duration time and waveform of airborne anvil can be determined through PU rubber (Figure 4) with different Shore hardness. Figure 5 shows shock acceleration of PU rubber with different Shore hardness, where 5(a) shows black rubber: the shock time is 0.5 ms to 0.8 ms and shock acceleration is about 1160 m/s^2 to 5980 m/s^2 ; 5(b) shows two-layer red rubber: the shock time is 3 ms to 4 ms, and shock acceleration is about 130 m/s^2 to 950 m/s^2 .

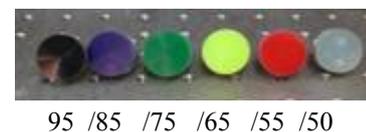
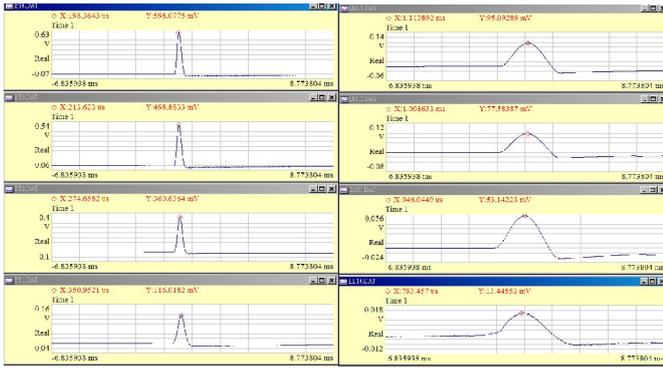


Figure 4 PU rubbers with different Shore hardness

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 150000 m/s^2 and a linear amplitude increment of 10000 m/s^2 about 0.1 %.



(a) Black PU rubber (b) Two-layer red PU rubber
 Figure 5 Shock acceleration is produced with two rubbers

In order to simulate mass for an accelerometer under calibration, the back end of a shock accelerometer installs a dummy mass (Figure 6). This mass can be designed as 20 g to 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 from 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 %.

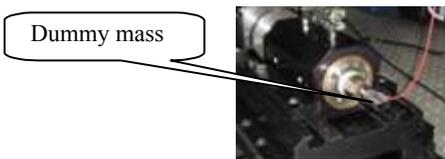


Figure 6 Installation of dummy mass for an accelerometer

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 [2].

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 $f_{max} = V_{max} \times 3.16 \times 10^6$. Therefore, the measuring bandwidth of photo detectors in this system is 150 MHz.

Figure 7 shows an illustration of optical interferometer. Figure 8 shows interferometer photo. 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 $\pm 5\%$. The phase difference should be 85° to 95° . $u_1(t)$ and $u_2(t)$ are as shown in Figure 9.

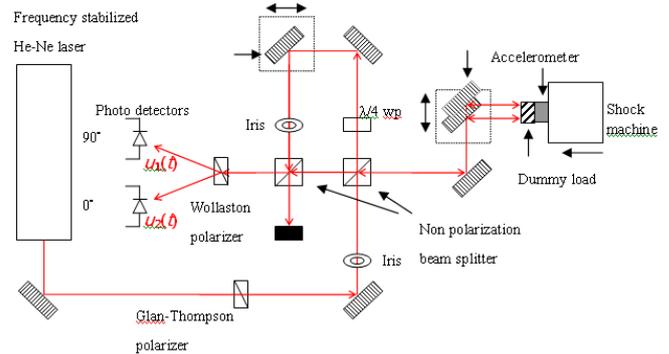


Figure 7 Illustration of optical interferometer

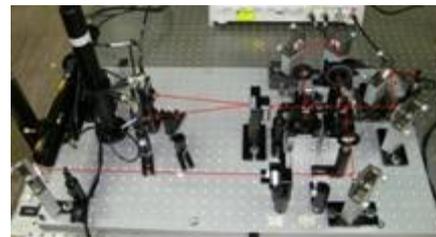


Figure 8 Interferometer photo

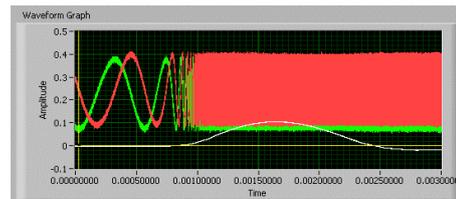


Figure 9 Interfering signal $u_1(t)$ and $u_2(t)$ of phase difference 90°

2.3. Digital Waveform Recorder

Through Lab View programming, PCI-NI 5922 Digital Waveform Recorder will be synchronously triggered by proximity switch to record voltage output from an accelerometer. PCI-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 $\phi(t) = \tan^{-1} \frac{u_1(t)}{u_2(t)}$. This phase is time-sequence data. Upon the phase is determined, the shock displacement is defined as $D(t) = \frac{\lambda}{4\pi} \phi(t)$.

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 [3]. 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. The filtering is as shown in Figure 10. The way to process accelerometer voltage sensitivity is as shown in Figure 11.

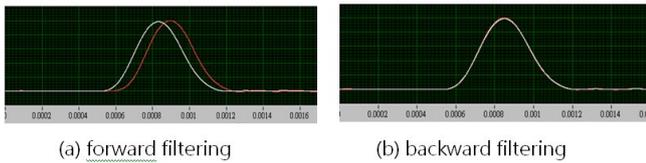


Figure 10 forward and backward filter

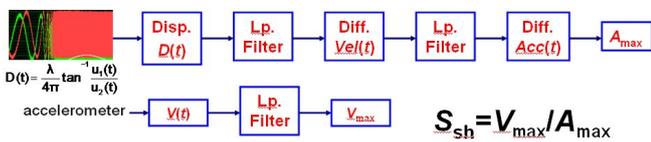


Figure 11 signal process for voltage sensitivity of accelerometer

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:

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

Where

- S_{sh} : Accelerometer set voltage sensitivity (mV/(m/s²))
- V_{max} : The voltage of maximum filtered accelerometer output (mV)
- A_{max} : The maximum calculated acceleration from interferometer signal (m/s²).

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 [5], the relative expanded uncertainties for the system are 1.0 % to the calibration measurement capability with the acceleration range from 200 m/s² to 5000 m/s².

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

NML has established the Primary Calibration System for Shock Acceleration, this system utilize electromagnetism excitation equipment to generate steady impulse force, then guide the hammer and anvil with rigid body motion collision in a alignment by air bearing support. 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/s² to 5000 m/s², the shock pulse duration time is less than 3 ms. The final evaluated relative expanded uncertainty is less than 1.0 % within coverage factor $k=1.96$. For the more complete industrial service and traceability we shall continue to improve and expand the system acceleration from 100 m/s² to 10000 m/s². To achieve this goal the different PU rubber pad (Figure 12) shall be replaced or changing the material of hammer and anvil from stainless to aluminium alloy.

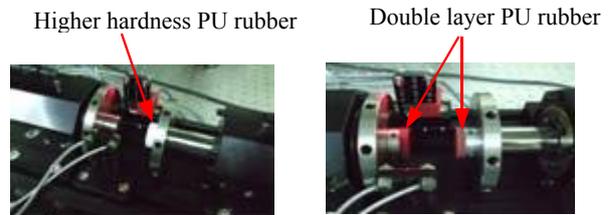


Figure 12. Expand acceleration range by replacement different PU rubber.

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