IMPLEMENTING A SHOCK-FORCE CALIBRATION SYSTEM

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Abstract

Abstract: The NMISA upgraded its dynamic force calibration system to satisfy new demands from local industry. As part of Land Mobility Testing (LMT), high impact force levels are measured. Improvements to the existing facility required the development and implementation of a system, able to deliver repeatable high impact forces, with a substantial payload. Further improvements included the development of a data capturing unit for the measurement of the impact pulses and determine the unit under test shock pulse sensitivity.

This paper will discuss the measurement methodology applied for the generation and measurement of shock pulses. The determination of the force required for the generation of these shock pulses is discussed, indicating the chain of traceability to the SI. The system performance is demonstrated. To conclude, data to validate the performance is provided together with an overview of the uncertainty of measurement estimation.

Keywords: shock, dynamic, force, calibration, land mobility, uncertainty of measurement.

1. Introduction

Force measurements are performed routinely by industry, mainly in modal analysis applications, where a system's response to a known applied force is determined. This applied impulse force causes the system to resonate at its natural frequencies, revealing pertinent and useful characteristics of the system. The system can be anything from a car door panel to aeroplane wing or a telephone handset.

The force is applied using a variety of devices of which an impulse hammer is but one. The NMISA had developed three impulse hammer calibration systems to satisfy industry requirements. Some land mobility testing is performed using an artificial limb, fitted with special strain gauge sensors for shock force measurements. These sensors were calibrated using static forces only which were inadequate as all sensors exhibit frequency and level non-linearities. In response to this demand from industry, one of the existing facilities was improved in order to insure that industry can perform traceable shock force measurements.

In order to meet the new requirements, the existing large impact hammer calibration system was completely revised into a shock-force calibration unit that can generate medium to high shock force pulses. The new calibration system can be used to calibrate a variety of force measuring device and sensors and boasts a complete new computer controlled signal generating, data capturing system and peak voltage measurement capabilities.

In this article the system parameters will be discussed along with the operating principle, measurement methodology and immediate improvements and advantages over the previous system. An overview of the uncertainty contributors will be given along of future system refinement plans.

2. System Description

The shock force calibration system is based on an anvil shock acceleration calibration techniques defined in [1]. For this shock force calibration application, the law of conservation of linear momentum applies and an elastic collisions are assumed. From classical mechanics

$$\vec{F} = \frac{\mathrm{d}}{\mathrm{d}t}(m\vec{v}) \tag{1}$$

Newton's 2nd law of motion, force equals mass times acceleration

$$\hat{F} = m \cdot \hat{a} \tag{2}$$

is put to use to determine the force exerted by the anvil, resulting in the measured acceleration of the pendulum. Whereby by;

1. having a pendulum with a known effective mass,
2. determining the peak acceleration of the pendulum,
3. the applied peak force is determined using (2),
4. from which the shock force sensitivity can be determined using (3)

$$S_S = \frac{\hat{U}_S}{\hat{F}} \tag{3}$$

2.1. System Parameters

2.1.1 Pendulum

Suspension cables

- i. Length: ≈ 2 m
- ii. Diameter: < 2 mm
- iii. Weight: ≈ 16 grams

Anvil dimensions:

- i. Length: 400 mm
- ii. Width: 100 mm
- iii. Height: 100 mm

Pendulum weight:

i. Anvil: 31,027 kg
ii. Mounting bracket: 510, 894 g
iii. Reference transducer: 31 g
iv. Total weight: 31,569 5 kg
(including the mounting brackets excluding the suspension cables)

2.1.2 Pulse exciter with power amplifier

- Peak acceleration: 50 m/s^2
- Max force rating: 133 N
- Frequency range: DC to 200 Hz

2.1.3 Peak Voltage Measurement

Analogue to Digital converter (AtoD)

- Sampling rate: 1 MS/s
- Number of samples: 500 000
- Analogue input bits: 12 bit
- Voltage input range: 0,2 V to 2 V
- Dual channel or single channel
- Single point 1 volt accuracy (1 year specification): 3 mV

Filter

- Type: Butterworth
- Order: 4^{th}
- Low pass cut-off: 1 kHz

2.1.4 Signal generator

Digital to Analogue converter (DtoA)

- Sampling rate: 100 kS/s
- Number of samples: 100 000
- Analogue output bits: 12 bit
- Voltage output: 10 V
- Output waveform: 10 ms pulse

2.1.5 Shock pulse

- Acceleration range: 100 m/s^2 to 100 km/s^2 [1]
- Maximum peak force: 3,5 kN
- Pulse width: 20 ms

2.2. System Block Diagram

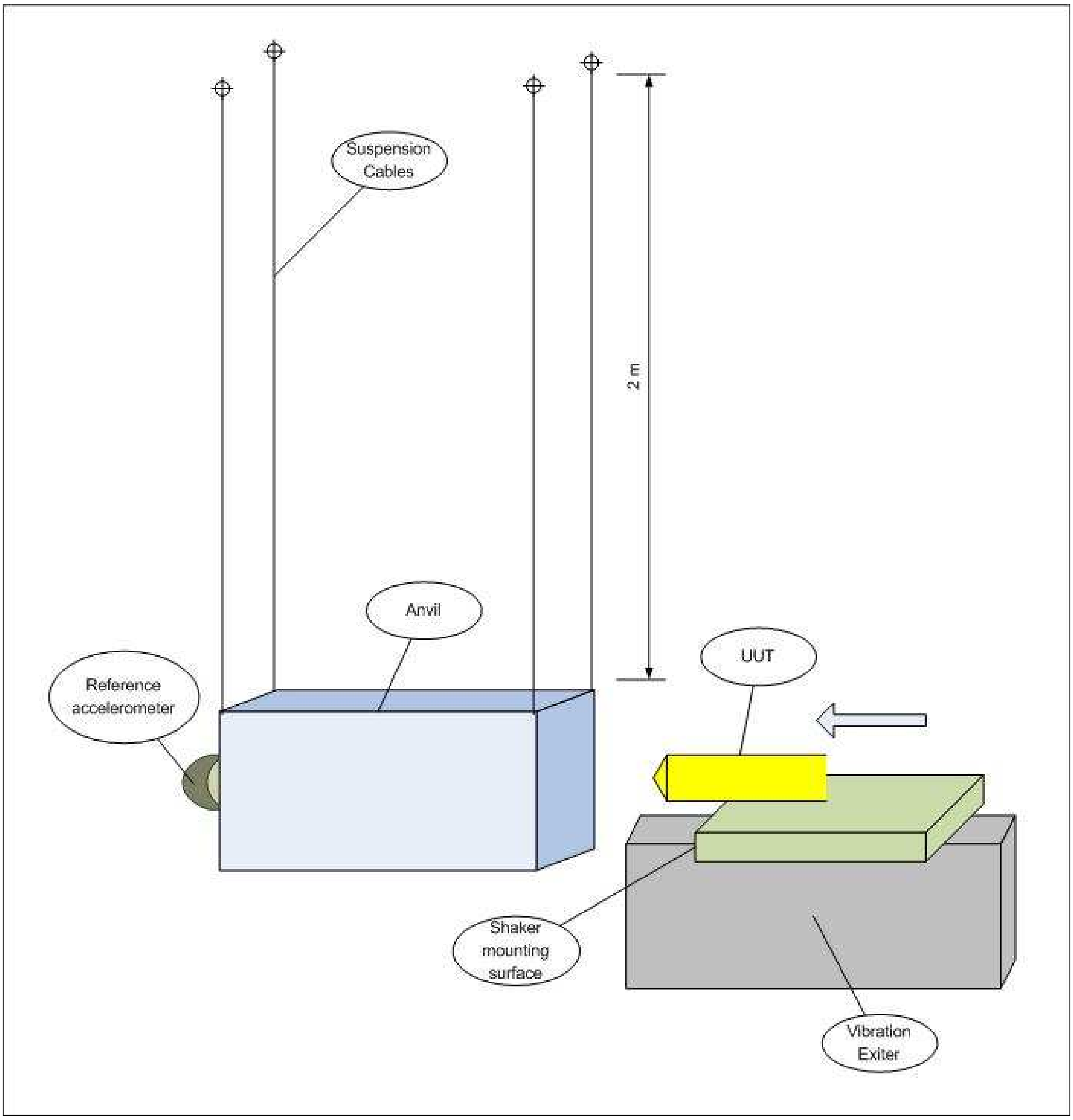

Figure 1: Block diagram of shock pendulum calibration system

2.3. Measurement Procedure

ISO 16063-22 describes 6 different apparatus that can be used for shock calibration, covering a wide range of acceleration levels. For anvil shock calibration apparatus, 3 different signal processing techniques are described for measuring the shock sensitivity;

- i maximum value as signal peak-value (time domain, peak)
- ii polynomial approximation (time domain, fit)
- iii FFT analysis (frequency domain, FFT)

For the software developed for this project, all three signal processing techniques were implemented, with the FFT option partially implemented at the time of this publication.

A measurement is initiated by sending a shock pulse to the vibration exciter. The AtoD is armed by a trigger pulse being send to the AtoD trigger channel some 10 ms prior to the actual shock pulse. This “pre-trigger” initiate the 500 ms data capturing period of the AtoD (500 MS at 1 MS/s). A 4th order Butterworth low pass filter is applied to the captured signals as a smoothing filter. A copy of the time signals are stored on the HDD to facility easy retrieval of the “original” data should re-measurement of the signals be required. Figure 2 shows a set of captured peak time series.

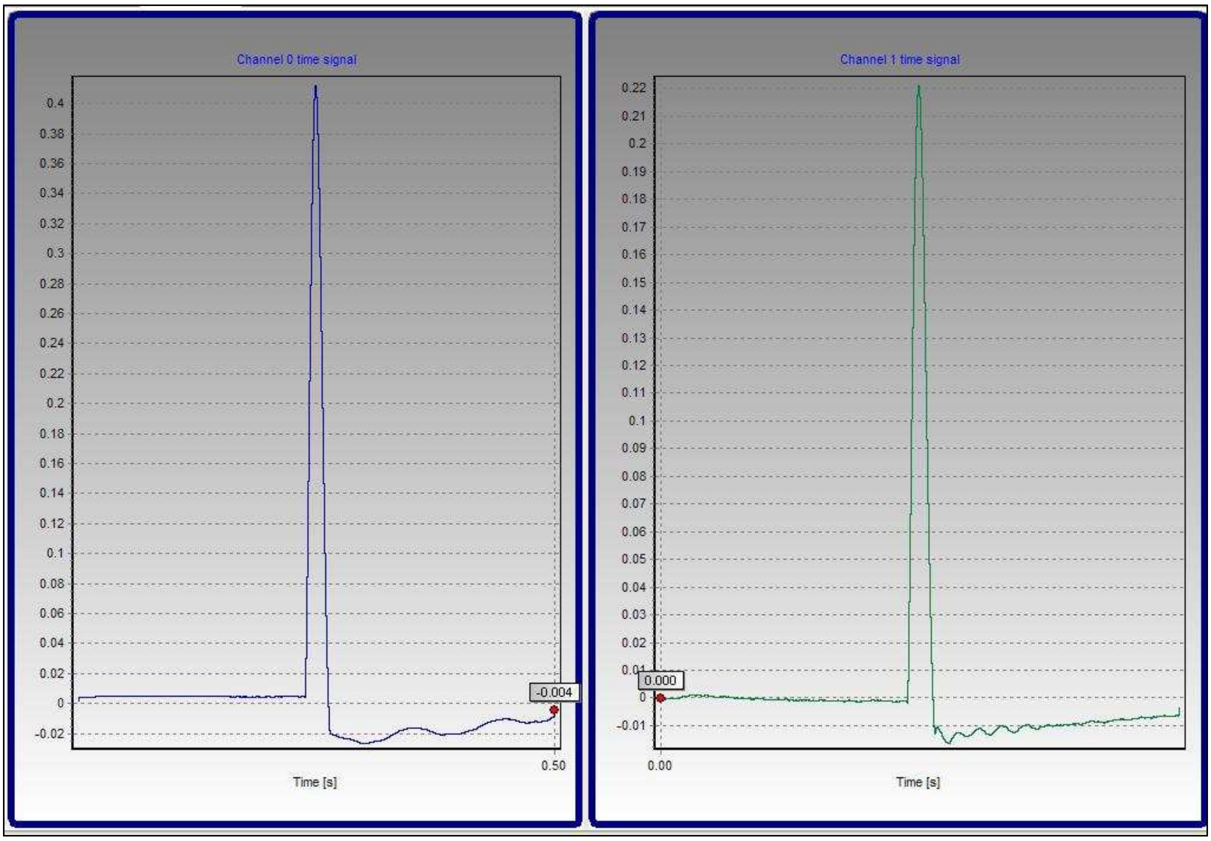

Figure 2: Captured reference and UUT time signals

All the unwanted sampled data is removed so that only the time signal containing the shock impulse is retained, see figure 3. Once the irrelevant time signal is removed, the signal processing is initiated, performing the peak and curve fitting routines (at the time of this paper, the FFT functionality was still under development). This is followed by the calculation of the sensitivity values using all the selected techniques (peak, fit and/or FFT), as well as the mean sensitivity of the selected techniques. The result of this processing is displayed in figure 3.

Currently, the results have to be recorded by hand, but full measurement result capture functionality will be implemented.

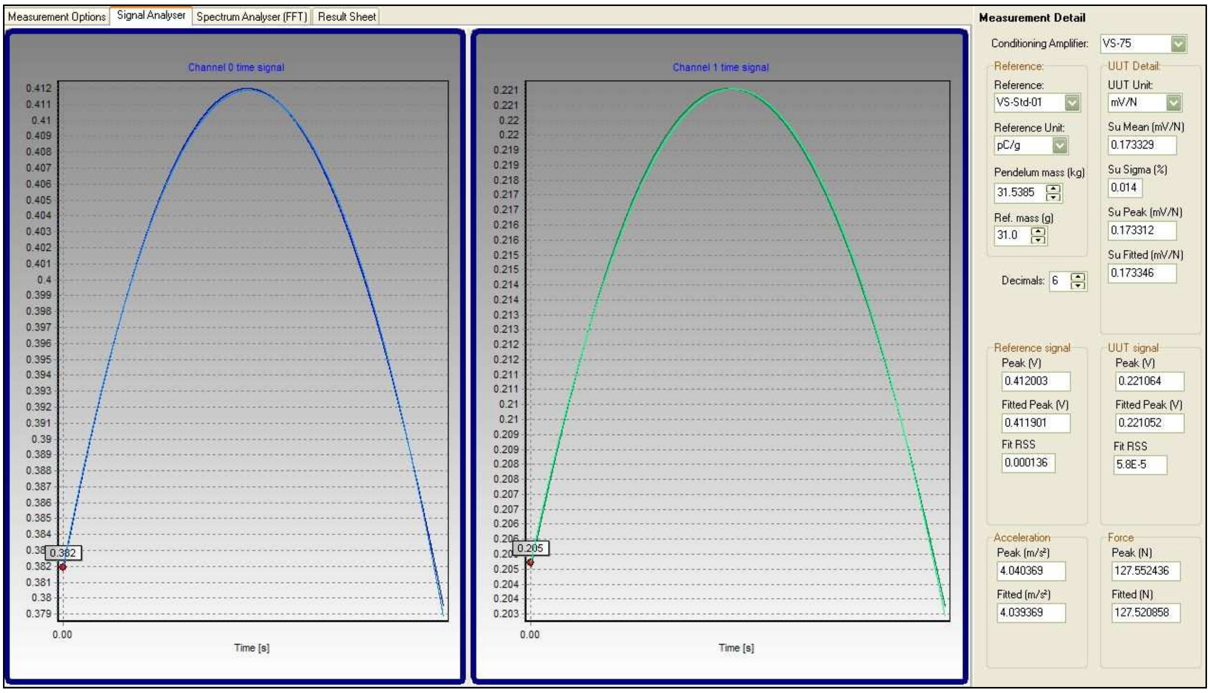

Figure 3: Post processing time signals

3. Overview of Uncertainty Contributors

The uncertainty contributors described in [1] were considered as a starting point, with some additional contributors which were identified as having a significant influence.

3.1 Mathematical model

$$S_S = \frac{S_R \cdot \hat{U}_S}{m \cdot \hat{U}_R} \qquad (4)$$

Where:

S_S = Shock sensitivity
S_R = Reference accelerometer sensitivity
$\hat{U}_S$ = Peak shock channel voltage (UUT)
$\hat{U}_R$ = Peak reference channel voltage
m = Anvil/pendulum mass

3.2 Uncertainty Contributors

3.2.1 Reference Transducer: This will be the expanded uncertainty as per the reference accelerometer's shock calibration certificate. This is the most significant uncertainty contributor.

3.2.2 Pendulum Effective Mass: The pendulum mass is measured and the total effective mass is determined. The weight of the suspension cables are taken as negligible.

3.2.3 Peak Voltage Determination: The pulse peak voltage determination accuracy. The DAQ card analogue input one year accuracy specification on the 1 V range is used.

3.2.4 Filtering: The filter should be optimally flat in the pass band. The influences on the peak signal determination is dependent on the filter order and its cut-off frequency and pass band flatness (type of filter dependent). For this application a 4^{th} order Butterworth filter was used with a roll off of 40 dB/octave in the stop band and negligible attenuation in the pass band. The cut off frequency was selected to be at least 4 times the impulse frequency.

For dual channel signal processing where the ratio of the two voltages is determined, the error due to filtering is dependent on the difference between the applied filters. Thus, if identical filtering is applied to both signals, even if a filtering error of 50% occurs per channel, the resulting error on the voltage ratio will be negligible.

3.2.5 Anvil Motion/Transverse Sensitivity: The anvil's motion is effectively a circle with a radius equal to the length of the suspension cables. This results in non-linearities in the motion of the anvil. This non-linear motion, combined with the transverse sensitivity of the reference transducer, results in a systematic error when determining $\hat{U}_{R.}$ The motion of the anvil is modelled as a compound pendulum with a small angle displacement, making the assumption that $\sin(\theta) = \theta$ possible.

3.2.6 Signal to Noise Ratio: For peak voltage method, the signal to noise level influences the peak voltage uncertainty. The noise is reduced by a factor of 5 by using digital filters.

3.2.7 Polynomial Fit Error: The RSS error calculated as an accuracy of the fit.

4. Performance Comparison

To validate the system performance, an impact hammer with known sensitivity was calibrated on the previous system. The most notable components contributing to the improved expanded uncertainty of measurement are compared in table 1.

Table 1: Comparison of major improved parameters

Parameter	**Previous system**	**New system**	**Improvement**
Voltage measurement AtoD	8 bits	12 bits	16x
Voltage measurement accuracy	0,5 %	0,25 %	2x
Repeatability	3%	1%	5x
Signal to noise (peak to peak noise)	50 mV	10 mV	5x
UoM	10%	3%	3x

The most noticeable improvement to the calibration system is the improved repeatability. This is achieved through the implementation of a vibration exciter on which the impact hammer is mounted to strike the anvil with instead of striking the anvil with the impact hammer by hand. This implementation of the shaker provides the ability to reproduce the impulse force more accurately, as well as the point of impact where the impulse hammer strikes the anvil.

The previous system utilised an oscilloscope to capture and determine/measure the peak voltages. Although the 1 MHz sampling rate of the oscilloscope used was sufficiently high, the 8 bit AtoD resolution was not optimal. Further more, the oscilloscope lack functionality to accurately "pin point" the peak of the votage time signals.

For the improved system, a 12 bit AtoD system was employed with custom software to determine the peak values of the voltage time signals. The time signals are captured and digitally filtered to improve the signal to noise ratio. Two methods are used to determine the peak values, as earlier discussed, with the functionality to use the mean peak value obtained from the two methods.

5. Conclusions

The existing impact force calibration system was successfully modified to improve the system repeatability and to reduce the estimated expanded uncertainty of measurement. As part of the upgrade modifications, the developments also took into consideration making the system divers to accommodate the calibration of other devices such as artificial limbs for Land Mobility Testing.

6. References

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