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IMPLEMENTING A SHOCK-FORCE CALIBRATION SYSTEM USING A VIBRATION EXCITER AND PENDULUM

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Abstract − The NMISA upgraded its impulse hammer calibration system to satisfy new demands from local industry for shock force measurements. 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 to determine the unit under test shock force 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, impulse hammer

1. INTRODUCTION

Force measurements are performed routinely by industry, mainly in modal analysis applications, where a system's response to a known applied force shock pulse is determined. This applied impulse 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 an aeroplane wing or a telephone handset.

The force shock pulse is applied using a variety of devices of which an impulse hammer is but one. The NMISA had developed three impulse hammer calibration systems enabling it to calibrate the wide size range of impulse hammers used in industry. Recently, a somewhat unique request to calibrate an artificial limb, fitted with special strain gauge sensors for shock force measurements, was put to the NMISA. At the time, these sensors were calibrated using static forces only, which were inadequate as all sensors exhibit a frequency response. In response to this demand, one of the existing impulse hammer facilities was modified to facilitate the calibration of these artificial limbs, 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 system, capable of generating medium to high shock force motions (50 N to 3 500 N). The new calibration system can be used to calibrate a variety of force measuring devices and sensors. It boasts with a complete computer controlled signal generating-, data capturing- and peak voltage measurement system.

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.

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 elastic collisions are assumed. From classical mechanics

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

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

$$\hat{F} = m \cdot \hat{a} \qquad (2)$$

is put to use to determine the amplitude of the shock pulse exerted by the hammer (or vibration exciter), 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)

$$\hat{S}_S = \frac{\hat{U}_S}{\hat{F}} \qquad (3)$$

2.1. System parameters

Fig.1 shows a diagram of the system.

Pendulum suspension cables:
  i.   Length: ≈ 2 m
  ii.   Diameter: < 2 mm
  iii. Weight: ≈ 16 grams

Pendulum dimensions:
  i.   Length: 400 mm
  ii.   Width: 100 mm
  iii. Height: 100 mm

Pendulum weight: 31,569 5 kg consisting of
  i.   Anvil weight: 31,027 kg
  ii.   Mounting bracket: 510, 894 g
  iii. Reference transducer: 31 g

Pulse exciter with power amplifier:
  i.   Peak acceleration: 50 m/s^2
  ii.   Max force rating: 133 N
  iii. Frequency range: DC to 200 Hz

Analogue to Digital converter (AtoD):
  i.   Sampling rate: 1 MS/s
  ii.   Number of samples: 500 000
  iii. Analogue input bits: 12 bit
  iv.   Voltage input range: 0,2 V to 2 V
  v.   Dual channel or single channel
  vi.   Single point 1 volt accuracy: 3 mV

Filter
  i.   Type: Butterworth
  ii.   Order: 4th
  iii. Low pass cut-off: 1 kHz

Digital to Analogue converter (DtoA):
  i.   Sampling rate: 100 kS/s
  ii.   Number of samples: 100 000
  iii. Analogue output bits: 12 bit
  iv.   Voltage output: 10 V
  v.   Output waveform: 10 ms pulse

Shock pulse:
  i.   Acceleration range: 100 m/s^2 to 100 km/s^2 [1]
  ii.   Maximum peak force: 3,5 kN
  iii. Pulse width: 20 ms

2.3. Measurement Procedure

ISO 16063-22 describes 6 different apparatus that can be used for mechanical shock calibration, covering a wide dynamic range of acceleration levels. For anvil shock calibration apparatus, 3 different signal processing techniques (DSP) are described for measuring the shock sensitivity;
  i.   maximum value as signal peak-value (time domain, peak)
  ii.   polynomial approximation (time domain, fit)
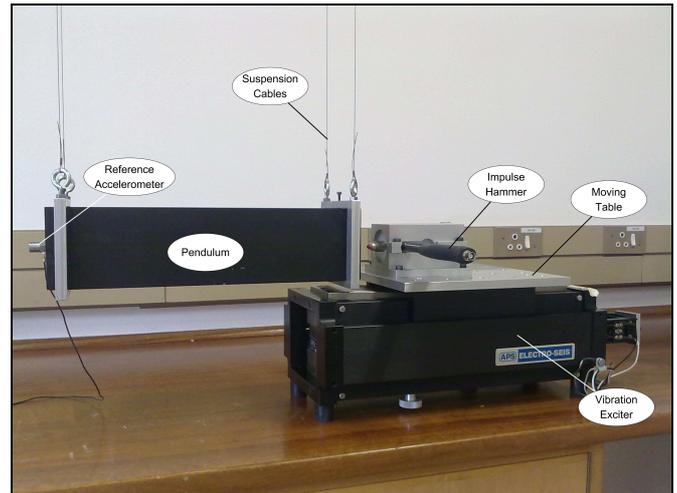 iii. FFT analysis (frequency domain, FFT)

Fig. 1. Pendulum mechanical shock calibration system.

For this system, measurement procedures i) & ii) of the ISO standard were implemented.

A measurement is initiated by sending an electrical 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 shock pulse to be captured. 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 captured data should the metrologist whish to perform the signal processing again, for instance with a higher order polynomial fit. Fig. 2 shows a set of captured time series of the peak signals.
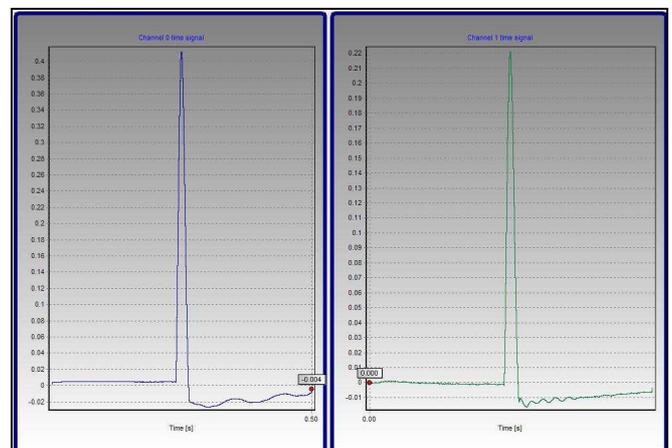

Fig. 2. Captured reference (channel 0) and UUT (channel 1) time signals.

All the unwanted sampled data is removed so that only the time signal containing the shock impulse is retained. See Fig. 3. Once the irrelevant time signal is removed, the signal processing is initiated, performing the peak and curve fitting routines. This is followed by the calculation of the sensitivity values using the selected techniques (peak and/or
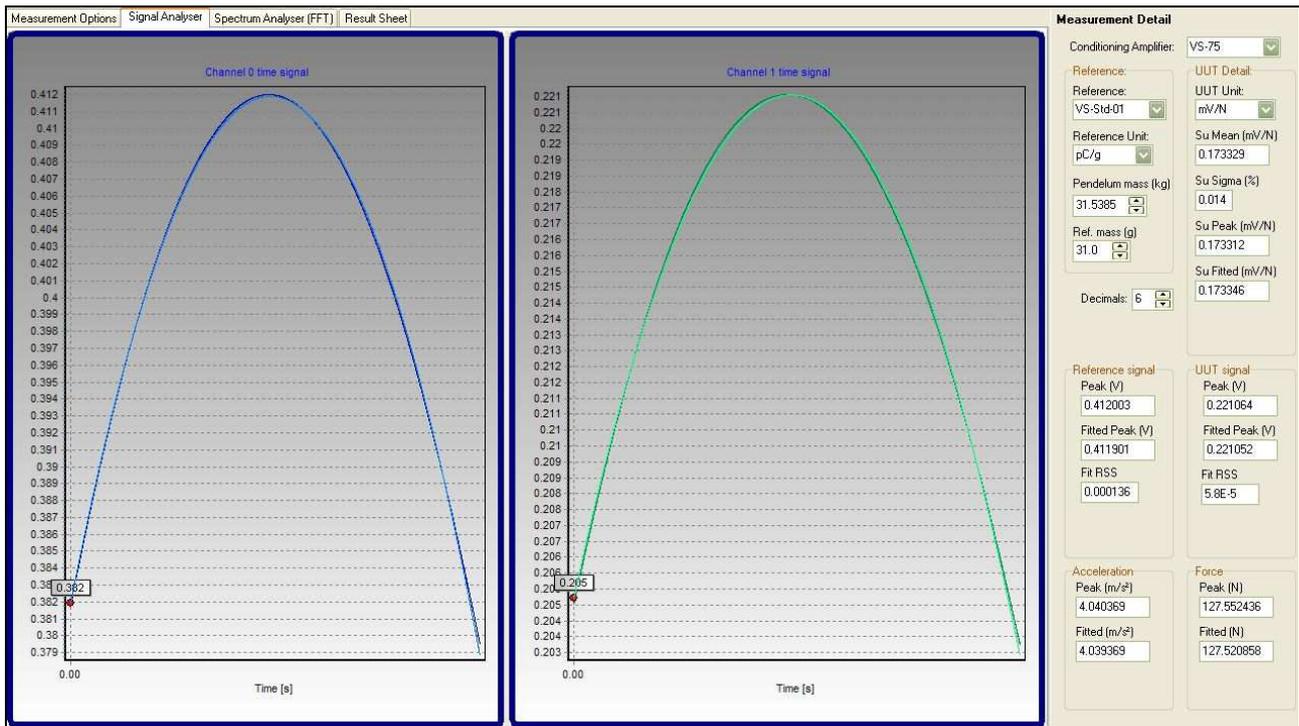
Fig. 3 Post processing time signals.

fit), as well as the mean sensitivity of the selected techniques. The result of this processing is displayed in Fig. 3. Five sets of measurements are recorded in an Excel spread sheet which serves as the result sheet for the measurements.

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

$$\hat{S}_S = \frac{\hat{S}_R \cdot \hat{U}_S}{m \cdot \hat{U}_R}$$

(4)

Where:

$\hat{S}_S$ = Shock sensitivity
$\hat{S}_R$ = 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

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

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.

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

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 4th order Butterworth filter was used with a roll off of 40 dB per 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 shock pulse 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.

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.

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.

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

6. REFERENCES

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