

Traceable low frequency AC voltage measurements

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Abstract

The International Organization for Standardization (ISO) has developed a set of standards for the calibration of vibration and shock transducers. Method 3 of ISO 16063 part 11, deals specifically with the primary calibration of accelerometers over the frequency range 1 Hz to 10 kHz. Many NMIs have implemented the method over a wider frequency range. One of the difficulties faced by said NMI, is the provision of traceable low frequency AC voltage measurements.

This paper considers low frequency AC voltage traceability options and investigates in more detail a measurement option defined as DC sampled AC measurements. As part of the investigation; 1) a calibration procedure is developed and implemented, 2) the measurement accuracy of the system is demonstrated.

Keywords: ISO 16063, vibration transducer, calibration standard, AC voltage, calibration, traceability.

1. Introduction

With the implementation of an accelerometer calibration system using laser interferometry, the three main quantities that are measured are; displacement, time and AC voltage. The displacement is obtained using laser interferometry, time is obtained by measuring the applied vibration frequency (excitation frequency) and taking the inverse of the measurement, $t = 1/f$. The AC voltage is measured using an AC voltage measuring instrument, typically a true RMS voltmeter. In the international arena, National Metrology Institutes (NMIs) in general have implemented their primarily accelerometer calibration systems in compliance with ISO 16063-11 [1]. This well developed standard provides all the technical requirements for the successful implementation of such a primary calibration system. Not only does it outline the specification requirements for individual components of the system, it also provides uncertainty budget matrixes, assisting in identifying and quantifying major uncertainty contributors.

ISO 16063-11 makes provision for the implementation of an accelerometer calibration system over a wide frequency (1 Hz to 10 kHz) as well as a wide dynamic range (0,1 m/s² to 1 000 m/s²). This standard also makes provision for the complex determination of the accelerometer's sensitivity, ie the magnitude and phase sensitivity. Through the careful implementation of the standard, Uncertainty of Measurement (UoM) of $\leq 1\%$ is obtainable. Leading NMIs have already demonstrated that an UoM of 0,1% is obtainable. For any measurement

to be performed with a total expanded UoM of 0,1%, the individual UoM contributors need to contribute less than 0,1% to the overall measurement.

Two important aspects of any measurement performed is its accuracy (more encompassing, it's UoM) and the traceability of the measurement. It is common practice for NMIs to implement primary calibration methods. An element of concern is the accurate measurement (small UoM) of the accelerometer's output voltage, with demonstrated traceability to the relevant national measurement standard, especially at low frequencies. Here, low frequency AC voltages are viewed as AC voltages with frequencies ≤ 10 Hz. In general NMIs offer AC traceability from 10 Hz upwards. Most of the "off the shelf" AC voltage meters (DVM) have adequate AC voltage specifications from 10 Hz upwards. Obtaining the phase information with a commercial DVM is very difficult.

The commonly used approach to overcome these difficulties is to use a high quality data acquisition system (DAQ) with analog to digital converter capabilities (AtoD). This is a convenient and cost effective solution. In applying method 3 of ISO 16063, the acceleration is determined by sampling the quadrature output signals of the laser interferometer. By using a DAQ with at least 3 AtoD channels, the "I" & "Q" signals as well as the accelerometer output voltage can be sampled simultaneously, providing one with the capability to determine both magnitude and phase information.

2. AC Voltage traceability options

For the AC voltage, various traceability options do exist. The techniques that were considered to calibrate the DAQ and also provide traceability were:

- Calibration against an AC reference source [2]
- Calibration against a transfer standard [3]
- DC calibration [4,5]

2.1. Calibration against an AC reference source

A low frequency AC voltage standard, similar to the system described in [2] would be required for the implementation of this method. The implementation of such a system was discarded due to

- cost implications
- this method fell in the realm of the DC Low Frequency laboratory of the NMISA

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2.2. Calibration against a transfer standard

DVMs with the capability of measuring low frequency AC voltage signals with a small UoM are available on the market. These instruments generally employ an AC/DC thermal transfer method. However the accuracy of the AC/DC thermal transfer method degrades rapidly for lower frequencies [6]. For more accurate AC measurements at low frequency, modern DVMs employ a DC sampling technique. The device is effectively operated as an AtoD in this mode.

Using a transfer standard to obtain traceability was discarded due to

- the larger UoM that will be obtained as the calibration will not be directly against a higher accuracy standard
 - the lack traceability at the time of implementation as the available unit was not calibrated for AC voltage below 10 Hz

2.3. DC Calibration

It is well known that it is possible to calibrate a DC voltmeter to a smaller UoM than is possible for an AC voltmeter. This method holds further advantages:

- Only one aspect requires calibration; the DAQ DC reference source.
 - The calibration is performed at a single point, nominally 7,5 V.
 - This calibration can be done with a smaller UoM than the AC equivalent.
 - DC Calibration is the manufacturer's recommended method.
 - A calibration procedure is available from the manufacturer's Webb site [4].

AC signals are generally analyzed in either the time domain or in the frequency domain. Frequency domain analysis employs Fourier analysis techniques. With these analysis techniques the amplitude of the measured signal can be determined. Although this method has the advantage of using a relatively low sampling rate (close to the Nyquist frequency), it does not meet the high accuracy requirement needed.

While time domain analysis employs AC estimation algorithms, the method requires a slightly different view with respect to the measurand and how the magnitude of the measurand is obtained. A measurement technique referred to as "DC sampled AC measurement" was implemented. In essence this involves using a sampling rate that far exceeds the Nyquist frequency.

If one assumed an infinitely high sampling rate, the time between two discrete samples will tend to become infinitely small, thus representing a continuous signal.

The magnitude and phase estimation of the measured AC signal was achieved using the sine-approximation method as described in [1]. The series of discrete AC voltage input values ($u[t]$) is approximated using the sine-approximation method. This is achieved by solving the following system of $N + 1$ equations.

$$u[t_i] = A_u \cos(\omega t_i) - B_u \sin(\omega t_i) + C_u \quad (1)$$

Where

$$A_u = \hat{u} \cos \varphi_u$$

$$B_u = \hat{u} \sin \varphi_u$$

C_u = a constant

\hat{u} = the AC signal amplitude

φ_u = the AC signal initial phase value

The voltage amplitude (\hat{u}) and initial phase (φ_u) is then calculated from the parameter values A_u and B_u using the formula

$$\hat{u} = \sqrt{A_u^2 + B_u^2}, \quad (2)$$

$$\varphi_u = \arctan \frac{B_u}{A_u}. \quad (3)$$

3. Calibration procedure

As indicated earlier, the calibration procedure implemented was based on the calibration procedure described by the manufacturer [4]. A software program was developed to implement the documented procedure as closely as possible. The detailed documented procedure describes a complete step by step procedure in terms of

- the equipment needed
- a 1 year specification performance evaluation, pre calibration
- the actual calibration procedure for the on-board DC reference
- a 24 hour specification performance evaluation, post calibration

The manufacturer's procedural document contains the detail required to correctly configure the DAQ. This detail include the sampling rate, number of samples to acquire, the software instruction to configure the DAQ as well as the measurement ranges, measurement points and the tolerance values for the device's 1 year and 24 hour specifications.

3.1. Calibration of the AtoD

The calibration procedure for the AtoD is completed in five simple steps:

Step 1: Execute the self calibration procedure

Step 2: Perform a 1 year specification check

Step 3: Calibrate the on-board DC reference against an external DC reference source. The DC reference source is the standards to which all subsequent measurements will be traceable to.

Step 4: Execute the self calibration procedure

Step 5: Perform a 24 hour specification check

Once step 3 is successfully completed, the DAQ is calibrated. Steps 4 & 5 are completed to verify the accuracy of the DAQ, ensuring that it meets the manufacturer's specifications.

4. Performance verification

The question still remains, how accurate are the DAQ AC voltage measurements, especially at low frequencies? To investigate this, AC voltage measurements performed using the DAQ was compared against AC voltage measurements performed using an 8½ digit digital multimeter (DMM). The DMM was setup to operate using the "Synchronously Sub-sampled Computed true rms technique". According to the manufacturer, the meter has a best accuracy of 0,01% over the frequency range 1 Hz to 10 MHz when operated in this mode. A performance valuation report on the device [5] substantiates the manufacturer's claimed accuracy levels.

4.1. Verification procedure

The DAQ and DMM was setup to simultaneously measure an applied sine wave from a signal generator. With the generator, AC signals were generated from 1 Hz up to 20 kHz in 3rd octave steps. A subset of the DAQ measurement ranges was covered (0,2 V up to 10 V). Signals ranging in amplitude from 20 mV up to 10 V were measured. Signal amplitudes of full scale deflection (FSD), 0,5xFSD, 0,2xFSD and 0,1xFSD were used as measurement points to compare the measurements obtained using the DAQ with the measurements obtained using the DMM.

All four channels of the DAQ were simultaneously compared against the DMM. The measurement setup is shown in figure 1.

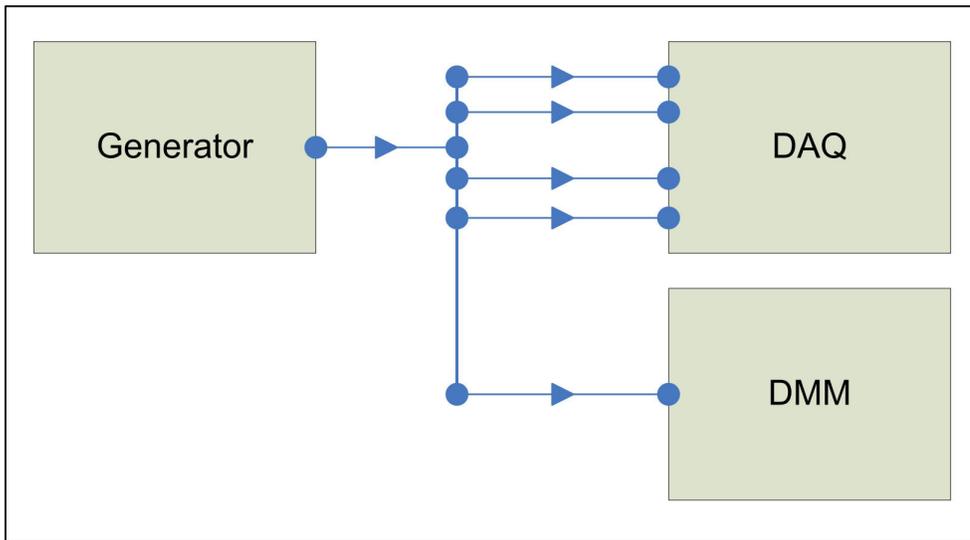


Figure 1: DAQ verification measurement setup

4.2. Verification results

The difference between the DAQ and DMM measurement results are shown in graphical format in figures 2 and 3. The results in figure 2 are the difference measurements for a 20 mV AC signal with the DAQ set to its 200 mV range (0,1xFSD). Figure 3 shows the difference measurement results for a 1 V AC signal with the DAQ set to its 1 V range (FSD).

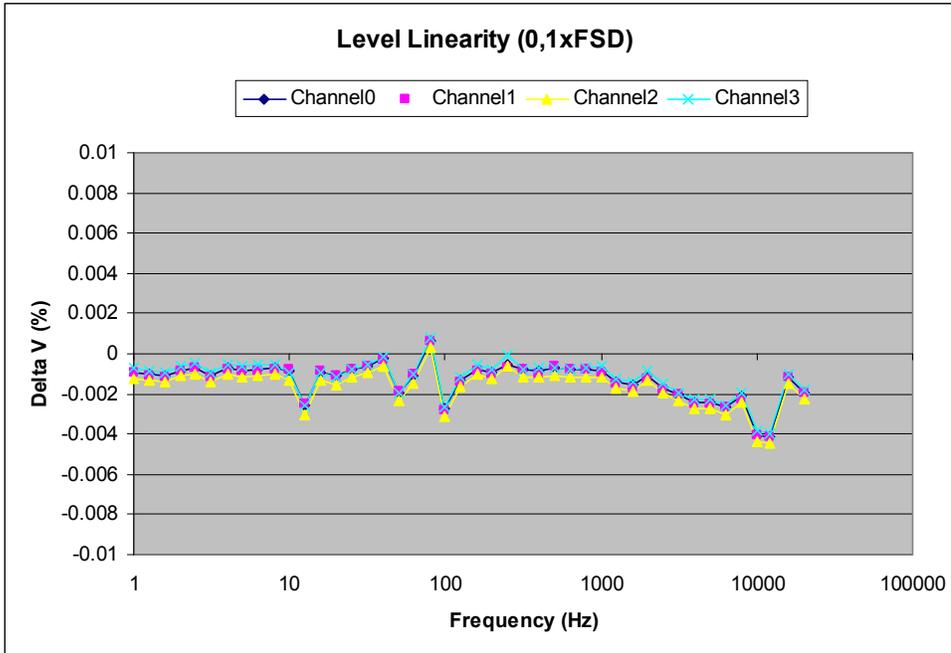


Figure 2: Difference measurement results of a 20 mV signal

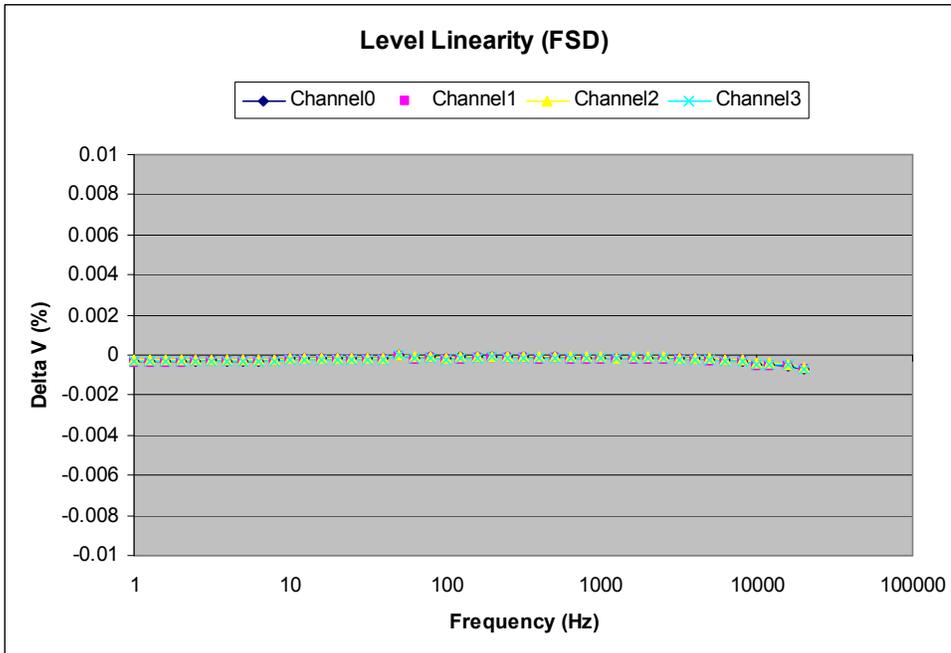


Figure 3: Difference measurement results of a 1 V signal

A total of 6 measurement ranges, from 0,2 V up to 10 V, were compared at 4 individual AC voltage levels each. All of the 24 measurement sets, covering the frequency range 1 Hz to 20 kHz had difference results smaller than 0,007%.

5. Conclusions

A calibration procedure for DAQ devices have been implemented with success. The method empowers the user of DAQ devices to implement an AC voltage measurement technique with proven traceability to DC voltage. When implemented in conjunction with appropriate signal analysis techniques, such as the Least Squares linear fit, measurement accuracies of better than 0,01% is obtainable over a wide frequency range for sinusoidal signals.

Figure captions

Figure 4: DAQ verification measurement setup

Figure 5: Difference measurement results of a 20 mV signal

Figure 6: Difference measurement results of a 1 V signal

References

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