NEW TECHNIQUES IN PRIMARY ACCELEROMETER CALIBRATION

Mark I. Schiefer

The Modal Shop

This paper will discuss a newly developed implementation of ISO 16063 style primary accelerometer calibrations. The goal is a laser primary accelerometer calibration system capable of performing low uncertainty primary accelerometer calibrations while maintaining the throughput and simplicity of a traditional back-to-back calibration system.

Primary accelerometer calibrations typically require multiple measurement passes at several locations across the device to be calibrated by primary means. This paper discloses the novel use of a dual beam, simultaneous primary calibration laser interferometer based system. The use of dual beam and multiple pass Michelson Interferometers greatly improves not only the reliability of the measurement, but significantly simplifies the setup and measurement process of primary laser calibrations of accelerometers.

Keywords

Accelerometer Calibration, Laser Interferometry, ISO16063

Introduction

Primary accelerometer calibration is at the root of traceability for virtually every accelerometer calibration chain in the world: commercial, government, military, academic or vendor. Acceleration calibration via laser interferometry is a primary method because it is an absolute method comparing the measured vibration from a sensor under test to a constant of nature – the wavelength of laser light. ISO 16063-11 [1] defines the international standard governing primary vibration calibration. Generally this methodology is used only to calibrate reference accelerometers intended to be used in the back-to-back comparison technique as defined in ISO 16063-21 [2]. Practical implementation of the comparison method is presented in further detail by Peres and Sill [3].

ISO16063 Part 11 Primary Vibration Calibration

The ISO16063-11 standard discusses three alternative methods for primary calibration. Each method requires increasingly more complexity in hardware as well as algorithm/analysis, and leads towards increased functionality such as inclusion of phase information and sub wavelength measurement resolution.

The traditionally employed technique is Method I – Laser Interferometry via Fringe Counting. The benefits of this method center around the use of relatively simple electronics in the form of counters to detect interference fringes in the reflected laser beam. ISO16063-11 specifies that this technique is only useful for a low frequency range (up to 800 Hz) but footnotes that it can be applied to higher frequencies under special circumstances – namely, the acceleration levels must be significantly increased at frequencies above 800 Hz. This method has an extremely low uncertainty contributed mainly by mechanical components rather than the electrical components.

Drawbacks to fringe counting are that it can only be used at low frequencies at which displacement is large enough for a significant number of fringes to be counted. This technique also provides no phase information.

ISO16063-11 – Method II – Minimum Point Method is extremely cumbersome and manually intensive, requiring the user to tune the acceleration amplitude to match the zero crossings of the laser. Because low transverse calibration exciters are incapable of providing the displacements fringe counting needs at high frequencies, this method is employed in the frequency range up to 10 kHz.

The primary benefit of this technique is that by utilizing a low frequency modulating mirror and compensating mathematics, the counting methodology can be extended into the higher frequency ranges. However, certain implementations require an exotic high g level piezoelectric shaker to attain the desired displacements at those higher frequencies. Clear drawbacks from commercialization include the complexity and durability concerns with the low frequency moving mirror to modulate the beam. Effectively, Method II is not able to be implemented practically.

ISO16063-11 – Method III – Sine Approximation Method originally required much more digitization and processing; however, this has become realizable with today's electronics. The fundamental benefits are that it can handle the complete frequency range (1 to 10k Hz) at reasonable acceleration levels and also measure phase information. Primary drawbacks to this technique are the increased costs associated with a general purpose laser vibrometer and an extremely high speed digitizer, the need for large amounts of memory for low frequency processing, and increased manual acquisition time due to speckle drop out on a non-cooperative target. For example, at 1 Hz with a 10 mm displacement, the required sample rate is approximately 300k samples/second with the number of samples being on the order of 6 megasamples to adequately measure just 2 cycles of the vibration waveform. This is obviously a huge computational load. Couple this with a probability of laser signal drop out due to speckle during data acquisition and the science of the calibration measurement often relies heavily on the art of fixture alignment. Even with these drawbacks, this methodology is emerging as the common choice for practical implementation given its fundamental benefits.

Vibration Exciter Considerations

For all of these methods, the position of the point of laser reflection is important, preferably at the plane of mounting. However, since the shaker might not have purely planar motion, multiple measurements may need to be made to determine or verify the planar motion of the device under test. Hence, the systems require either time consuming multiple measurements to be made or multiple laser heads. Additionally, significant attention and investment is made to provide an electromechanical exciter which minimizes transverse motion to the greatest extent. Electromechanical flexure-based shakers commonly used for comparison calibration are the “weak link” due to poor signal quality. For primary calibration, appropriate signal quality is accomplished with the use of a new generation air-bearing calibration grade exciter [4] shown in Figure 1.

Undesirable shaker characteristics, such as excessive transverse motion and waveform distortion, adversely affect the accelerometer calibration results. Transverse motion limits are required by ISO 16063-11 to be less than 1% for frequencies below 10 Hz, less than 10% for frequencies below 1000 Hz and less than 20% for frequencies below 10 kHz. Undesired transverse motion, bending and rocking modes of traditional flexure-based shakers can easily be greater than 100% of the primary axis motion at frequencies corresponding to a flexure or armature resonance, as shown in Figure 2. This large cross-axis motion, coupled with the inherent transverse sensitivity found in the accelerometer under test, will cause increased uncertainty and measurement errors at certain calibration frequencies in the response curve. It follows that when making high accuracy measurements, particularly for primary calibration, a reliable air bearing calibration shaker is one of the most important components in the entire measurement system.

Improved Implementation of Primary Vibration Calibration

Recent advances in laser interferometer hardware have allowed for an improved implementation of the sine approximation method in 16063-11. The extreme data acquisition and signal processing chores referenced previously can be readily overcome by judicious use of new real-time, hardware-based digital signal processing. Laser encoder hardware employing internal signal processing can be utilized to provide digitally encoded quadrature outputs in lower frequency ranges. At higher frequencies the analog quadrature outputs are measured. This distribution of the signal processing tasks directly into the interferometer hardware greatly simplifies and accelerates low frequency primary calibration while preserving all of the advantages of Method III.

Traditional primary calibration systems have employed just a single laser, requiring manual adjustment and reposition of the beam for spatial averaging to effectively deal with transverse motion at the measurement surface. By utilizing two lasers, a dual beam approach greatly simplifies the measurement process. Time savings are achieved because measurements are made at multiple locations simultaneously, with the resulting average processed in realtime. Additionally, this methodology removes any inaccuracies associated with the assumption of mechanical stationarity over time, i.e. the transverse motion is consistent.

There are many variants of Michelson interferometers. These include homodyne, heterodyne, single-pass and multi-pass. This new embodiment incorporates a homodyne multi-pass design interferometer. There are three distinct and significant advantages with this implementation. First, the multi-pass design separates the beams by approximately 7 mm. This provides inherent spatial averaging, achieved optically rather than by manual reposition of the laser. The second advantage is the effective doubling of displacement measurement resolution due to the physics of the multi-pass optics [5]. Lastly, the simplified homodyne design is more reliable due to reduced component complexity requiring no periodic calibration.

In lay terms, four red dots are better than one. By effectively making four simultaneously measurements and processing the results in realtime (instead of three or four individual measurements post processed), this implementation of primary vibration calibration, shown in Figure 3, allows the metrologist to calibrate in a single pass just like an automated, back-to-back comparison calibration.

An apparent limitation of this approach is the requirement for cooperative target preparation, i.e. polishing or placing mirrors on the accelerometer mounting surface. Laser interferometers traditionally integrated for primary vibration calibration applications claim to work with non-cooperative targets. However, in reality, the target must be somewhat cooperative; and, for best results, as cooperative as possible. Marginally cooperative targets result in unexpected signal drop outs due to changes in surface reflectivity. This requires longer averaging and specialized single processing in attempts to detect drop out occurrences. Drop outs reduce signal to noise ratio. It is simpler and more reliable to just properly prepare the surface from the start.

Conclusion

This improved implementation of ISO 16063-11 Method III has successfully simplified primary vibration calibration, making the calibration measurement more reliable, time efficient and cost effective. Nuances associated with fixture alignment and recognition of poor data quality have impeded the broader adoption of laser interferometry for improved vibration calibration. It has historically been too much art, not enough science, requiring a metrologist to spend hours instead of just minutes making calibration measurements. With new hardware technology integrated as presented here, primary level uncertainties are attainable with the throughput and simplicity of a production style, back-to-back comparison technique.

References

[1] ISO 16063-11 Methods for the Calibration of Vibration and Shock Transducers- Part 11: Primary vibration calibration by laser interferometry

[2] ISO 16063-21 Methods for the Calibration of Vibration and Shock Transducers- Part 21: Vibration calibration by comparison to a reference transducer

[3] Shock and Vibration Calibration of Accelerometers, Marco Peres & Robert D. Sill, Long Beach, CA, USA, Measurement Sciences Conference 2007

[4] Air Bearing Shaker for Precision Calibration of Accelerometers, Jeff Dosch, St. Louis, MO, USA, International Modal Analysis Conference 2006

[5] <u>The Laser Doppler Technique</u>, L. E. Drain, John Wiley & Sons Ltd, Chichester, UK 1980.

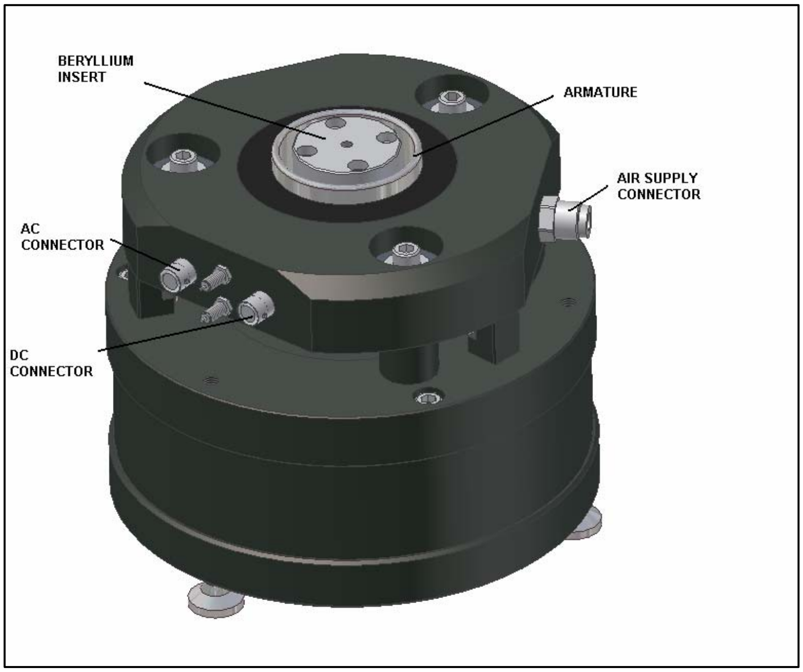

Figure 1. Illustration of The Modal Shop air bearing shaker (models K394A30 and K394A31).

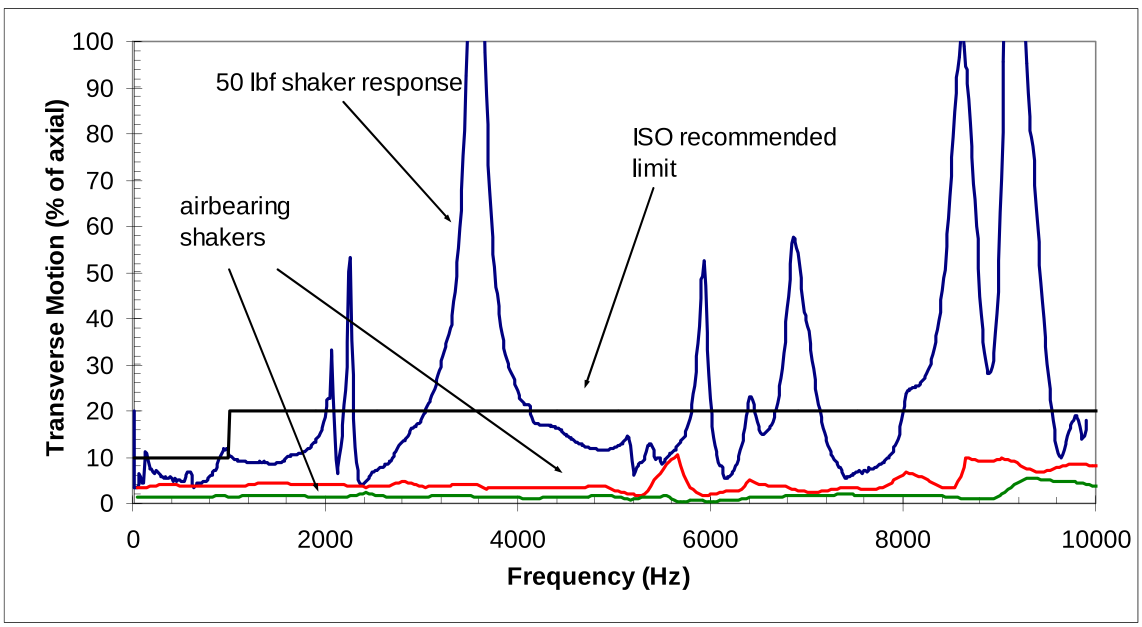

Figure 2. Transverse motion comparison of flexure based electrodynamic calibration shaker to The Modal Shop air bearing shakers, shown with the ISO 16063-11 recommended limits.

Figure 3. Top view of The Modal Shop 394A30 air bearing shaker, showing implementation of dual beam multi-pass laser for primary vibration calibration.