Single Point Optical Calibration of Accelerometers at NIST

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ABSTRACT

Typical accelerometer calibrations by laser interferometer are performed by measuring displacement at three places on the shaker table. Each of these measurements, made along the perimeter of the accelerometer, requires repositioning and realigning of the interferometer. This is done to approximate the actual displacement of the accelerometer. Using a dual-coil shaker with a small moving element and two coaxially-located and rigidly-attached mounting tables allows placing the accelerometer on one table and measuring displacement directly on the center axis of the second table. This was found to work effectively at lower frequencies, up to about 5 kHz, with mounting tables of conventional materials such as stainless steel. However, for higher frequencies the use of steel results in unwanted relative motion between the two mounting tables. Mounting tables of beryllium with nickel coating have been used at NIST to overcome this difficulty. This paper shows the calibration results of single point, on-axis measurements, using fringe counting and sine-approximation methods. The results compare favorably with three point measurements made by fringe disappearance using a conventional piezo-electric shaker at frequencies up to 15 kHz.

Keywords: accelerometers, calibrations, fringe-counting, interferometer, sine-approximation.

1. INTRODUCTION

National Institute of Standards (NIST) offers calibration services for accelerometers over a wide frequency range. For low frequencies of 1 Hz to 160 Hz, fringe-counting is used on an electrodynamic low frequency shaker. For frequencies from 10 Hz to 10 kHz, NIST offers a comparison calibration utilizing two electrodynamic shakers each of which have internal accelerometers which are calibrated by laser interferometry and reciprocity.

For frequencies from 3 kHz to 10 kHz, NIST has used fringe-disappearance interferometry since the late 1950’s using small piezo-electric shakers [1] designed at NBS (NIST). By 1969, piezo-electric shakers had been developed for wide-frequency range calibrations. By using a combination of damped resonant ceramic cylindrical elements, the shakers were useable up to 50 kHz [2]. Using this wide-range shaker, NIST was able to extend the range of the fringe-disappearance system to 20 kHz for typical accelerometers, and to about 25 kHz for smaller high frequency accelerometers of 10 g or less . This extended calibration service has been available at NIST since about 1984 [3].

Previous work at NIST [4] for primary calibration of accelerometer reported the development of a dual-coil shaker. This shaker has the features necessary for calibration by optical interferometry and reciprocity. References [5] and [6] describe the use of fringe counting and minimum point method for frequencies up to 5 kHz on the same dual-coil shaker. This paper will discuss the use of single point interferometric measurements using fringe counting, minimum point method, and sine-approximation methods to extend the measurement frequency range to 15 kHz.

2. MULTIPLE POINT CALIBRATIONS

Traditionally the laser interferometer calibrations at NIST are obtained by measuring the displacement at three or more places on the shaker table (Figure 1). This gives an average representation of the displacement experienced by the accelerometer. This technique is used on piezo-electric shakers, designed at NIST, for fringe-disappearance measurements. The piezo-electric shakers are designed to operate over a wide frequency range with exceptionally uniform motion across the shaker table, and provide sufficient

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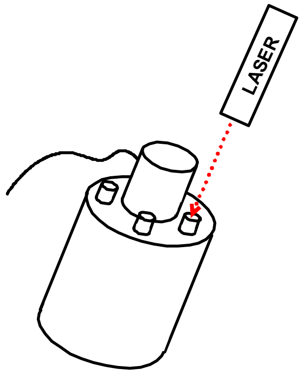
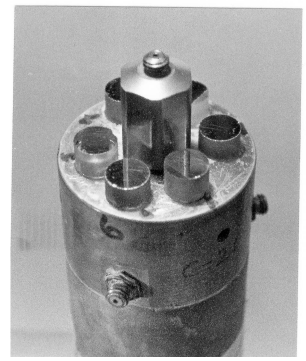
amplitude for fringe-disappearance measurements. This makes possible calibrations at higher frequencies up to about 20 kHz. NIST continues to use the method of fringe-disappearance [3].



(1a)



(1b)

Figure 1. Piezo-electric shaker with accelerometer mounted on mounting table setup for multiple point measurements.

3. SINGLE POINT CALIBRATIONS

The shaker in Figure 1a represents a conventional shaker, such as the piezo-electric shaker in Figure 1b, with a single mounting table and a driving element on the opposite end of the mounting table. Another approach is shown in Figure 2 using a dual-coil shaker. Here the accelerometer is mounted on the table opposite the reflecting mirror. Using reflection from the center of the mirror will enable one to accurately measure the displacement of the accelerometer provided there is no relative motion between the surfaces of the two tables. Tests conducted at NIST have shown that relative motion is experienced between tables fabricated from stainless steel or aluminum for frequencies higher than 5 kHz. Using a mounting table fabricated from beryllium with nickel plating provides for smaller relative motion between the tables in the setup of Figure 2.

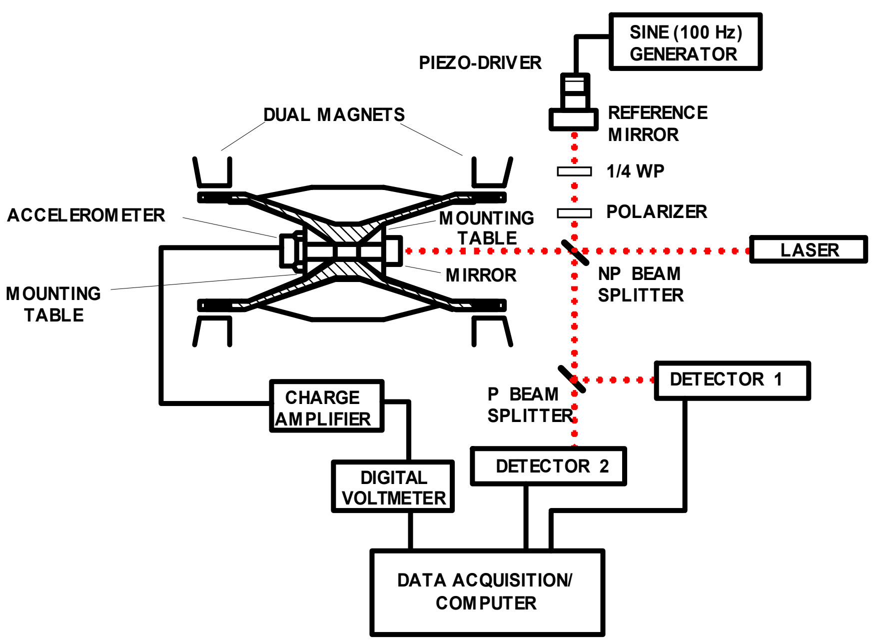


Figure 2. . Dual-coil shaker with accelerometer mounted on left mounting table and flat mirror on the right table.

Using the setup shown in Figure 2, one can obtain calibration data using the dual coil shaker, for frequencies up to 5 kHz, using fringe counting and minimum point methods by monitoring the output from detector 1 or detector 2. These methods and procedures are documented in other NIST publications [5,6] and in ISO 16063 - Part 11 [7]. In order to calibrate at frequencies higher than 5 kHz, the sine-approximation method is used. This method is useful at higher frequencies where calibrations at smaller displacements need to be made due to amplitude limitations in electro-dynamic shakers. The current implementation of the NIST dual-coil shaker limits the acceleration to approximately 200 m/s^2.

Figures 3 and 4, below, show an example of a single-ended-accelerometer calibration. The fringe-disappearance 3-point method, traditionally used by NIST for higher frequency measurements is compared to the single point method on the dual-shaker using fringe counting and sine-approximation methods.

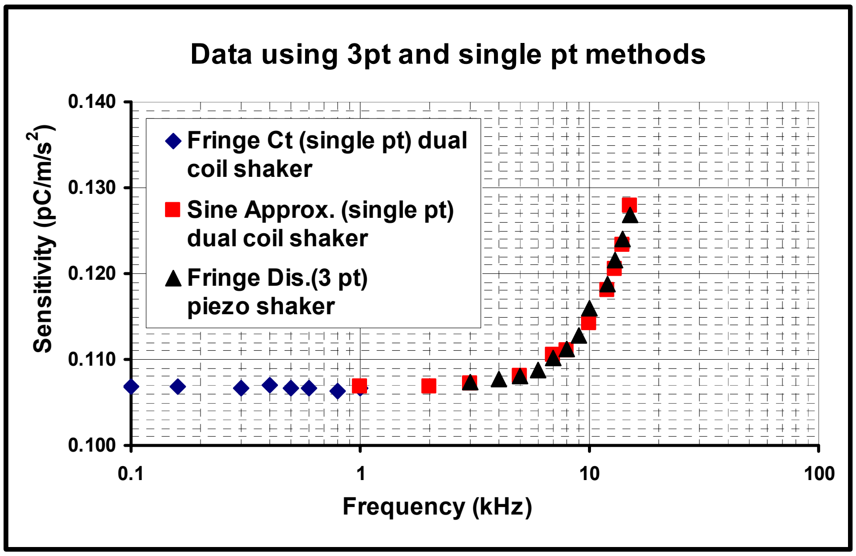


Figure 3(a). Data for an accelerometer mounted on a Be table in the dual-coil shaker using fringe counting and sine approximation methods (single pt measurements) compared to data from fringe-disappearance (3 pt) method on a piezo shaker.

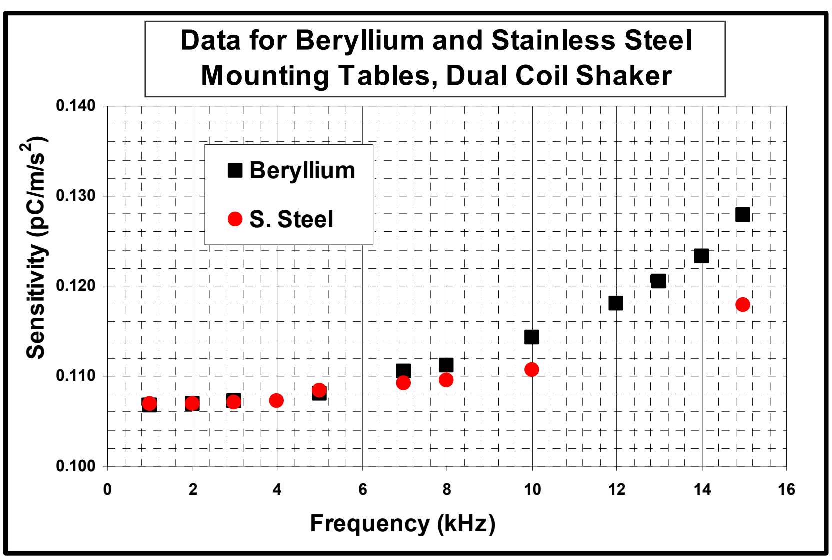


Figure 3(b). Differences obtained using stainless steel and beryllium mounting tables for the same accelerometer.

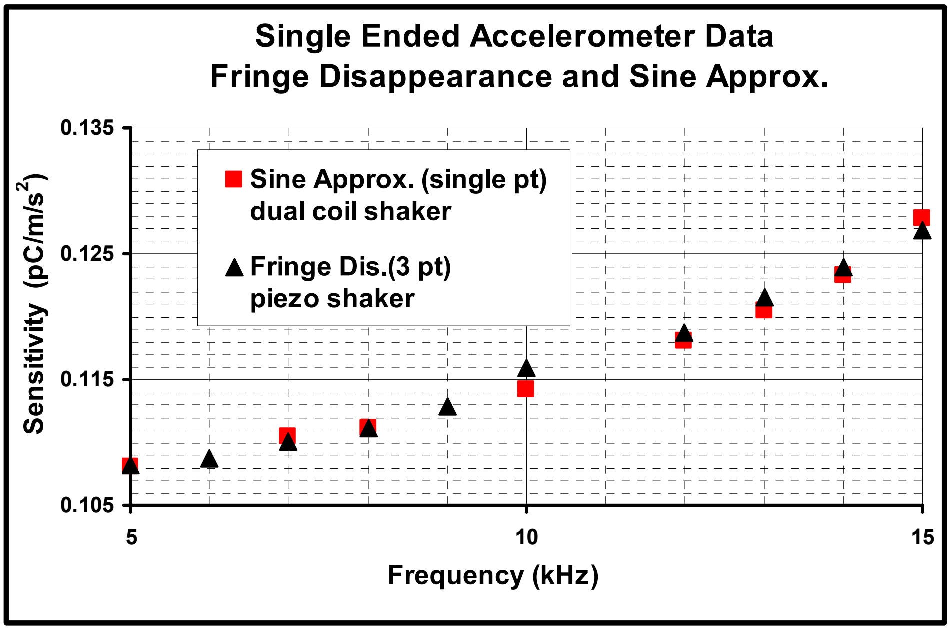


Figure 4a. Close-up of Figure 3a showing differences in the two calibrations for the 5 kHz to 15 kHz range.

In Figure 4a, (a close-up of Figure 3a) above, showing the data from 5 kHz to 15 kHz, the 10 kHz data point, using the fringe disappearance, is higher than would be expected. This deviation is due to a minor resonance in the piezo shaker. The dual-coil shaker does not have resonances in this frequency range resulting in data that better fits the general frequency response pattern. Also Figure 4b, below, shows the larger difference at 10 kHz due to the piezo shaker resonance.

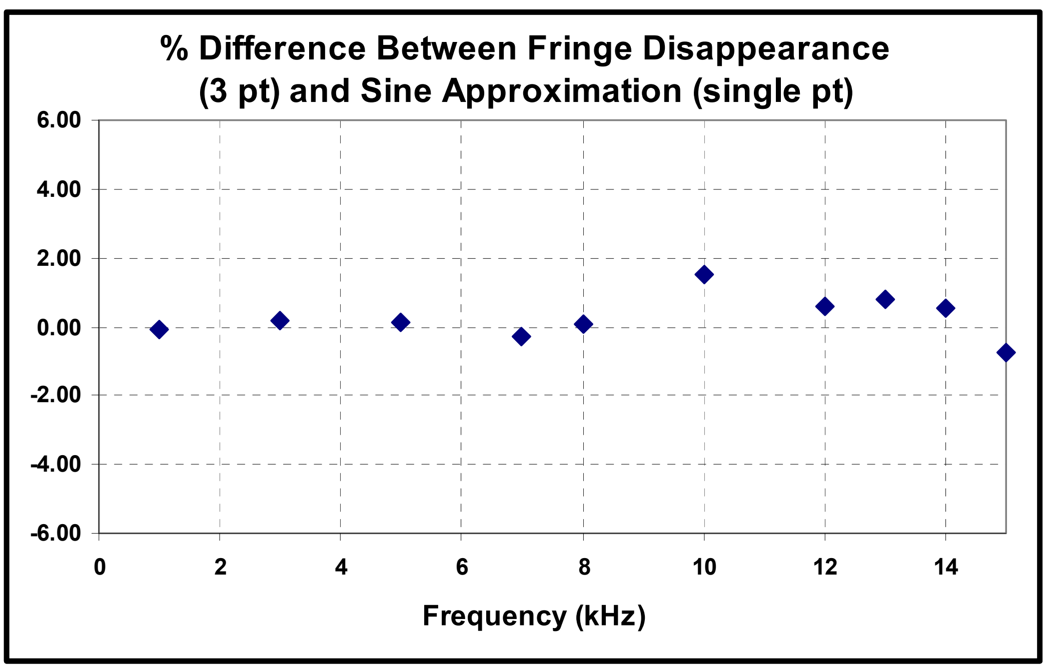


Figure 4b. Percent differences between data using fringe disappearance method (3 pts) on a piezo shaker and sine approximation method (single point) using Beryllium mounting tables on the dual-coil shaker.

The combined relative uncertainty for both the fringe-counting and sine approximation methods was calculated in accordance with methodologies described in the Guide to the Expression of Uncertainty in Measurement [8] using Type A and Type B evaluations of uncertainty components, including those contained in ISO documents on the calibration of vibration and shock transducers. For the fringe-counting method, using a coverage factor of 2, the estimated expanded relative uncertainty, U, at 100 Hz is 0.3 %. For the sine approximation method, again using a coverage factor of 2, the estimated expanded relative uncertainty, U, at 1 kHz is 0.5 %, at 5 kHz is 0.75 %, and at 10 kHz is 1%.

4. SUMMARY AND CONCLUSIONS

The fringe-disappearance system using the piezo shakers, described above, requires measurements of displacement at three or more positions on the shaker table. In addition, many measurements are required, at each position, to obtain the displacement corresponding to the condition of minimum light contrast. The resulting calibrations are time consuming. A dual-coil shaker developed at NIST provides for calibrations using displacement measured at a single axial point on the shaker using fringe-counting (10 Hz to 1 kHz) and sine approximation method (1 kHz to 15 kHz). Minimum point method calibrations are also available (1 kHz to 5 kHz). These single point calibrations are more easily obtained and the results compare favorably with multiple point measurements on piezo shakers for frequencies of 3 kHz to15 kHz.

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