LOW FREQUENCY ACCELEROMETER CALIBRATION CHALLENGES, ANALYSIS AND NEW DEVELOPMENTS

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Abstract: Low Frequency accelerometer calibration is generally time consuming and requires special considerations and excitation techniques. A new class of reference sensor for use in low frequency accelerometer calibration is introduced. This paper also outlines challenges of low frequency calibration and details principal sources of error. New developments in low frequency accelerometer calibration excitation technology are introduced. Comparison to manufacturers primary calibration of an artifact as well as comparison to primary means is presented.

Keywords: Accelerometer Calibration, Low-Frequency, reference sensor, linear motor, optical, encoder

1. INTRODUCTION

The general problem of low frequency calibration can be broken into two basic issues. The first is low frequency inherently means low acceleration amplitude. Acceleration decreases as a quadratic function of frequency and is exciter stroke limited [1]. The second is that low frequency calibration consumes a considerable amount of time due to the simple fact that periods of oscillation lengthen dramatically as calibration frequency decreases.

2. LOW ACCELERATION LEVELS

It is a well known and understood fact that the uncertainty of a back to back comparison [2] accelerometer calibration is dominated by the uncertainty of the reference sensor employed in the calibration. Low frequency calibrations typically require high sensitivity reference accelerometers of 500mv/g or better. The reference accelerometer frequently used for low frequency calibrations is the Honeywell Q-flex series of servo accelerometers. Fortunately the accelerometers being calibrated typically have a rather high output sensitivity and thus tend to not be the limiting factor in low frequency accelerometer calibrations. Figure 1 below graphically illustrates the challenge of decreasing acceleration level as a function of frequency.

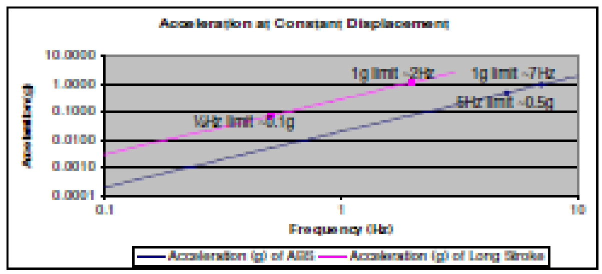

Figure 1 – Constant Displacement Acceleration

3. SOLUTIONS TO LOW ACCLERATION LEVELS

There are several potential solutions to the low acceleration level problem. One would be to dramatically increase the displacement used in the calibration. Dramatically increased displacment has been the solution employed at PTB, NIM China, and recently CENAM. The problem with this approach is that 1 meter long-stroke shakers are quite expensive, and typically require significant support overhead in order to operate. Another solution would be to implement a gravity rotator as described in [3] but this solution is limited to a rather low frequency range and comes with the added complexity of slip-rings and a rather massive support infrastructure requirement.

As mentioned above, the reference accelerometer is typically the limiting factor in low frequency back to back calibrations. One could simply switch to primary calibration at low frequency, but this would incur significant cost and complications as are typically encountered in a laser primary system. Clearly there must be a better solution.

What if one were to employ a displacement reference, but without the complexity and expense of a laser interferometer? Displacement transducers are notoriously noisy, non-linear, and have poor dynamic performance in general. Let us introduce the concept of an optical linear displacement transducer. These devices have become quite common within the machine tool industry and thus are quite robust and cost effective. There are at least three global manufacturers of these optical displacement transducers and their typical resolution is on the order of 10nm under typical best-case circumstances. Furthermore the technology is quite commonplace, not export restricted, quite robust and thus suffers from none of the limitations of prior reference devices utilized for low frequency calibration. A diagram of a typical optical linear encoder system is shown in Figure 2.

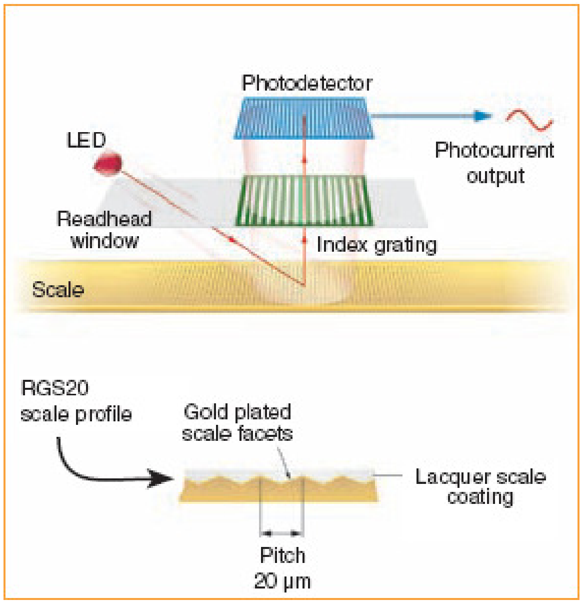

Figure 2 Diagram of Renishaw Linear Encoder System

4. IMPLEMENTATION OF REFERENCE SENSOR

The reference sensor is implemented in various fashions, depending upon the particular vintage or design of the vibration exciter being employed. In the case of traditional long-stroke shakers, the encoder tape is affixed to the moving armature of the shaker. The optical read head is then affixed to the stationary part of the shaker platform. The key issue being the assumption of "stationary". It is of prime importance that the structure to which the read head is attached be stationary. Any motion of the read head will compromise the accuracy of the displacement measurement and thus the calibration result.

An alternative implementation may be considered for other shaker architectures in which the read head is attached to the moving armature and the optical encoder tape is affixed to the stationary part of the shaker body. The same consideration with respect to motion of the "fixed" part of the displacement reference applies. For those familiar with primary calibration techniques, this consideration should be quite familiar.

Regardless of the implementation method, the output of the Linear Encoder System is quadrature in nature with a 1volt peak to peak amplitude and a period of 20um which can be interpolated down to 10nm. Again, for those familiar with Laser Primary Calibration methodologies and implementations, this technology integrates into a primary capable system quite nicely.

5. COMPARISON OF RESULTS

Several comparisons have been performed as to the performance of the displacement encoder implementation. One was at The Modal Shop, and the other at NPL India. Both employed an APS Dynamics 113AB as the long-stroke vibration exciter with the optical displacement encoder retrofitted to the exciter as the reference. Both comparisons utilized a PCB Q353B51 ICP™ Quartz Shear accelerometer as the comparison artefact. The artefact was primary calibrated at the manufacturer's primary laboratory in the PCB factory. Results for all three laboratories were nearly identical. It should be noted that neither the TMS nor NPL India laboratory employed any sort of building vibration isolation or seismic mass as has been previously described in the literature. Thus the results are fairly impressive given the laboratory conditions.

The validation of the observed calibration results on the system with that of manufacturers result for the same transducer was conducted for ascertaining the performance of the system and deviation in the results sought on the Primary system. PCB Q353B51 500 mV/g quartz ICP accelerometer in conjunction with an ICP sensor signal conditioner 480C02/7454 was calibrated on the system. It can be observed in fig 1 that deviation of 1 % exists between the PCB values and present system at 0.5 Hz attributed to the low signal to noise ratio with reduced acceleration levels and noise floor of sensor being calibrated. These deviations in the calibration results gradually decrease to 0.4 % at 100 Hz.

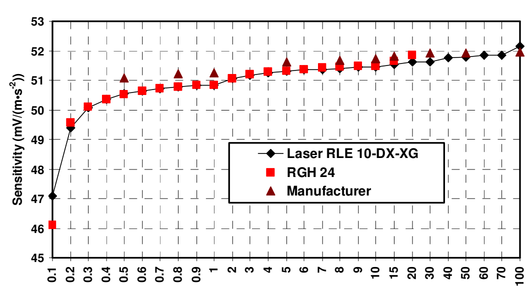

Figure 3. Comparison of the sensitivity (mV/ (m•s^{-2})) results for PCB Q353B51 sensor (S. No. 143969) on TMS system with laser RLE10-DX-XG; with RGH 24 sensor and manufacturer (PCBs) results.

The experimental run shows a deviation of 7 % in determination of sensitivity at 0.1 Hz as compared to sensitivity at reference frequency of 1 Hz. The standard deviation of five measurement runs taken was observed to be 0.39 % at 0.1 Hz, which gradually decrease to 0.23 % at 0.5 Hz. The ultra low frequency measurements (0.1 Hz to 1 Hz) have to be however validated from the key comparison with other prestigious NMIs realizing the primary vibration standard in this range for validation of the system capabilities. It can be also observed that the calibration runs with RGH 24 sensor also compare well with that of PCBs values (<1 %) in frequency range 0.1 Hz to 20 Hz, after which the deviations are quite large attributed to the reduced displacement with increasing frequency and resolution of optical encoder reference based directly upon displacement.

6. TIME CONSUMING OPERATION

We still have not addressed the time consuming nature of low frequency accelerometer calibration. Classic implementations require that the calibration system drive the long-stroke vibration exciter at some frequency and amplitude, measure the amplitude, adjust and repeat the cycle until the correct vibration amplitude is achieved. This technique is presently utilized in nearly all accelerometer calibration systems, both primary and secondary. The technique works well except at low frequency when the periods of oscillation are quite long and thus the control loop closure to target vibration calibration amplitude becomes quite time consuming.

7. THE LINEAR MOTOR SOLUTION

Like Optical Linear Encoders, the technology of linear motors has evolved significantly in recent years. Linear motors have replaced traditional ball and screw type drives for high performance machining centres in many applications. Linear motors utilize position feedback in the form of linear position encoders in order to control their motion in real time. Linear motor implementations typically will affix the optical encoder strip to the fixed portion of the motor track as shown in Figure 4.

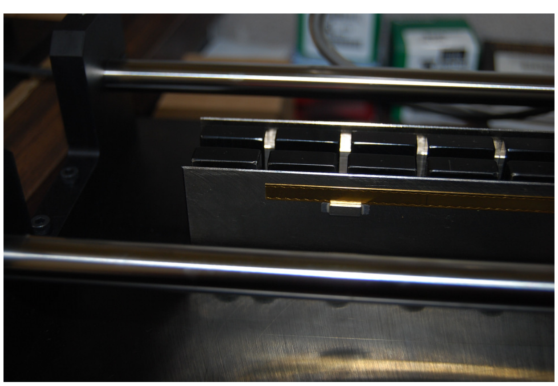

Figure 4. Close-up of optical encoder strip affixed to linear motor track assembly.

There are two significant advantages of using a linear motor in the implementation of a low frequency long-stroke exciter. The first is that due to the servo position controlled nature of the linear motor architecture there is absolutely no ambiguity about either the position or stroke (acceleration amplitude) of the exciter. The second is that stroke (displacement) may be arbitrarily increased as the application demands.

The concept of using a linear motor as the basis of a low frequency calibration exciter is not a new one. Usuda and associates have previously reported on the use of such a linear motor [5]. The Modal Shop has implemented a new generation of low frequency long-stroke exciter which is marketed as the 2129E025 long-stroke shaker. The device utilizes the RGH24 Optical Linear Encoder as both the position feedback for the integral servo controller and as the reference for low frequency calibrations.

Figure 5. TMS 2129E025 long-stroke shaker

8. PERFORMANCE OF THE 2129E025 LINEAR MOTOR EXCITER

In order to evaluate performance of the 2129E025 shaker system, a simple comparison similar to that previously described by the author was carried out at the Modal Shop's Laser Primary Calibration facility. A PCB Q353B51 ICP™ Quartz Shear accelerometer was used as the comparison artefact. A further evaluation of upper frequency calibration capability was carried out using both the Modal

Shop's Laser Primary as a reference, and a PCB 301M26 500mv/g double ended accelerometer as a reference. The results are shown graphically in Figure 6.

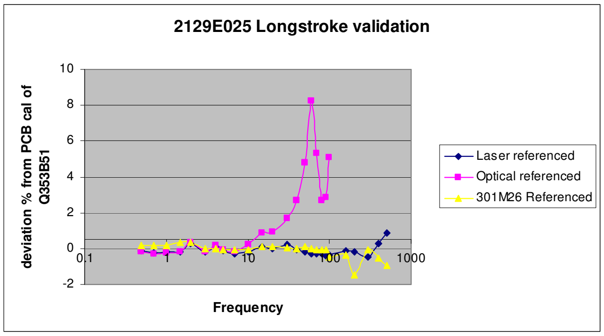

Figure 6. Calibration deviation from PCB Primary using three different references on TMS 2129E025 long-stroke shaker.

As can be seen from the graph, all three references agree quite nicely with the PCB primary calibrated Q353B51 artefact calibration up to about 20 Hz. After this frequency, the optical encoder as a reference begins to deviate significantly due to encoder resolution and read-head dynamics issues.

Regardless of the encoder performance, one can see that utilization of either the Laser, or 301M26 accelerometer as a reference provides excellent results for the entire usable frequency range of the 2129E025 shaker.

9. REFERENCES

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