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Improved Reciprocity Calibration of Accelerometers to Very High Frequencies

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The reciprocity calibration of piezoelectric accelerometers using two piezoelectric transducers was reported in detail by Harrison, et. al. in David Taylor Model Basin Report 811, dated August 1953. The calibration was tedious and time consuming, and has been improved in some respects in the proposed method as follows:

1. Only two frequency response functions have to be determined, if the mass of the piezoelectric stack of the reciprocal transducer is known.
2. The measurement of charge, rather than voltage and current, prevents possible errors due to stray capacitances.
3. With the introduction of FFT analyzers, such as the HP 3562A, the frequency response function of the two measurements can be stored and mathematically processed, and the calibration can be performed expeditiously.

The sensitivity of two accelerometers has been determined in the frequency range of 1 to 30 kHz with an estimated accuracy of 0.5% to 7 kHz, 1% at 10 kHz, 4% at 20 kHz, and 9% at 30 kHz. Results agree very closely with data obtained by NIST using the laser interferometric fringe disappearance technique. The frequency limits are dependent on the size of the apparatus.

The apparatus shown in Figure 1 consists of a small accelerometer 'A' mounted in a tungsten housing* with accelerometer 'B' firmly attached to the end of the housing. In the first measurement the softly suspended assembly is driven by applying a voltage to 'A' and the ratio of the voltage received from the amplified accelerometer 'B' to the driving voltage is determined. The second measurement provides the ratio of the outputs of the two accelerometers when the assembly is driven by a vibration generator attached to the free end. From these two measurements, the voltage to charge conversion of a charge amplifier, and a mass term, the sensitivity of both transducers can be derived.

Accelerometer 'A' does not contain an internal amplifier and is the device used as a transmitter in the first measurement and a receiver in the second. Based on the concept of reciprocity, the force generated per volt applied to accelerometer 'A' equals $s_q\omega^2$, s_q being the charge sensitivity and ω being the angular frequency. The acceleration of the apparatus neglecting wave effects is the force divided by the mass M, which is the total mass of the assembly minus the seismic mass and one half of the piezoelectric stack mass of accelerometer 'A.' This acceleration is sensed by accelerometer 'B' having a voltage sensitivity s_v. Thus, the ratio of the received voltage to the transmitted voltage is $s_q s_v \omega^2/M$. Using the "Automath" mode of the HP 3562A analyzer, the ratio is divided by ω^2 and stored in the analyzer as

$$G = s_q s_v/M \qquad (1)$$

A plot of G is shown in Figure 2 and its value should be constant at low frequencies; if not, it is an indication of electrical crosstalk problems. At 1 kHz, for example, the ratio of the received to the transmitted signal was −115 dB, and therefore ground loops must be avoided by the use of battery powered supplies and a floating input of one channel of the analyzer unconnected to an oscilloscope. The analyzer's crosstalk at 1 kHz is −141 dB. Using battery powered or ground isolated amplifiers for the receiver or stepping down the measured input voltage to the transmitter will reduce the crosstalk requirements of the analyzer.

In the second measurement, the ratio H of the output voltage of accelerometer 'B' to the output voltage of accelerometer 'A' is established by driving the assembly with a vibration generator, with accelerometer 'A' connected to a charge amplifier containing a feedback capacitor of value C (C is the inverse of the voltage output per charge input of the wideband charge amplifier).

$$H = s_v C/s_q \qquad (2)$$

A plot of H is shown in Figure 3. From equation (1) and (2): $s_q = (G/H\,MC)^{1/2}$ = charge sensitivity of accelerometer 'A' in coulomb/meter/sec^2, $s_v = (GH\,M/C)^{1/2}$ = voltage sensitivity of accelerometer 'B' in volt/meter/sec^2, $(G/H\,M/C)^{1/2}$ = voltage sensitivity of accelerometer 'A' at the output of the charge amplifier, M is in kg, and C is in coulomb. All computations can made using the math function of the HP 3562A analyzer.

At very high frequencies, wherever the ratio of the dimensions of the apparatus to the wave length is no longer small compared to unity, wave effects should be considered. No corrections have been made here, but the estimated correction at 20 kHz is −2% and at 30 kHz −4%. Recently a smaller apparatus has been constructed with a useful frequency range to over 40 kHz.

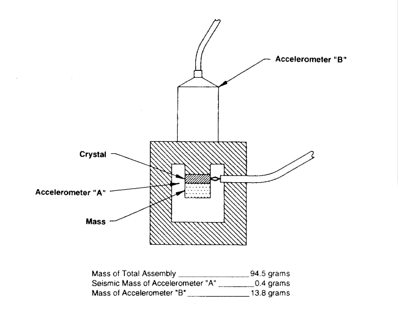

Figure 1. Reciprocity calibration apparatus.

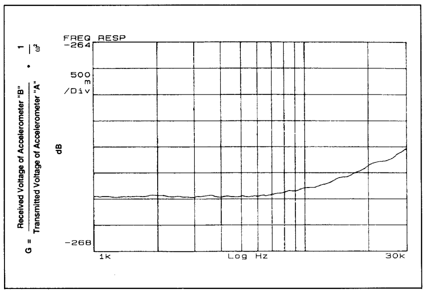

Figure 2. Plot of 'G'.

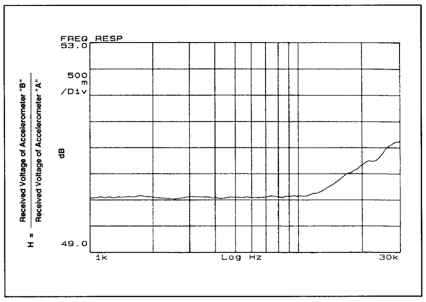

Figure 3. Plot of 'H'.

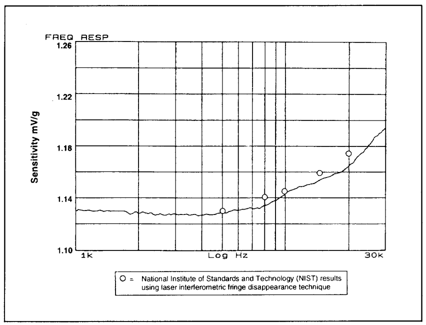

Figure 4. Sensitivity of accelerometer 'A'.

Figure 4 is a plot of the voltage sensitivity of accelerometer 'A' at the output of its charge amplifier with the circles indicating the results obtained by NIST using the laser interferometric fringe disappearance technique. The largest uncertainty at the lower frequencies is the value of the dynamic mass of the connecting cables. This uncertainty is estimated at 0.3%. At higher frequencies the transverse motion of the vibration generator probably causes erroneous signals, but these errors can be reduced.

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*Tungsten has a high product of elastic modulus and density, which is desirable for high frequency reciprocity calibrations.