AUTOMATED TESTING OF ACCELEROMETER TRANSVERSE SENSITIVITY

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ABSTRACT

A new system for automated testing of accelerometer transverse sensitivity has been designed and implemented at PCB Piezotronics. This paper describes the transverse test system theory, construction, and operation. Transverse sensitivities obtained from the automated system and sensitivities obtained by the manual method described in ISO 5347-11:1993 were found to agree to within the stated uncertainty of 0.3%.

NOMENCLATURE

a_i	linear acceleration	[g]
α_i	rotational acceleration	[radian/s^2]
S_i	linear sensitivity	[mV/g]
Ψ_i	rotational acceleration	[mV/rad/ s^2]
SUT	sensor under test	
v_o	SUT output	[Volts]
φ	Interferometer phase	[radian]
S	sensitivity	[mV/g]
g	acceleration constant	[9.80665 m/s^2]
ω_c	excitation frequency	[radian/s]
Re( )	real part of ( )	
Im( )	imaginary part of ( )	
( )*	complex conjugate of ( )	
subscripts:		
x,y,z	coordinate axes	
t	transverse direction	

INTRODUCTION

A number of final calibration tests are performed by an accelerometer manufacturer to ensure the quality and accuracy of the sensor used by the test engineer. Final calibration of an accelerometer for “test and measurement” applications may include testing of sensor sensitivity, frequency response, time constant, resonant frequency, and transverse sensitivity.

The trend in modal testing is for increasingly large channel counts and the consequent demand for lower cost sensors. The challenge to the sensor manufacturer is to reduce the sensor cost without sacrificing quality and sensor accuracy. Because of the costs involved in final calibration, rather than testing on a 100% basis, some sensor manufacturers have addressed the cost challenge by statistical sampling of some of their final tests. Where feasible, PCB Piezotronics has addressed the challenge in a different way and that is to automate the final calibration testing, and thus allow cost-effective final calibration of each sensor manufactured.

This paper describes a new automated system for testing of accelerometer transverse sensitivity. The system uses a resonant beam to generate uniform motion in the transverse plane. The beam motion is controlled and data is acquired via computer-based acquisition and control. Compared to the manual method used previously, the new approach has been found to provide more accurate and consistent calibration in the production environment.

THEORY

Ideally, an accelerometer will respond only to motion along its sensing axis. In the non-ideal world an accelerometer may respond to axial acceleration in a direction perpendicular to the main sensing axis and to rotational acceleration. Consider the accelerometer with the desired sensing axis oriented in the z direction (Figure 1) and subject to both linear and rotational acceleration. Output from the sensor will be equal to:

$$v_o = \begin{bmatrix} S_x & S_y & S_z & \Psi_x & \Psi_y & \Psi_z \end{bmatrix} \begin{bmatrix} a_x \\ a_y \\ a_z \\ \alpha_x \\ \alpha_y \\ \alpha_z \end{bmatrix} \qquad (1)$$

Where a_i and α_i are the linear and rotational acceleration components S_i and Ψ_i are the accelerometer’s sensitivity to these accelerations. For most piezoelectric accelerometers the rotational sensitivity, Ψ_i, is small and can be ignored. In such instances, only linear acceleration components contribute to sensor output:

$$v_o = \begin{bmatrix} S_x & S_y & S_z \end{bmatrix} \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} \quad (2)$$

For the sensor with sensing oriented along the z-axis, the maximum transverse sensitivity has a magnitude equal to S_t (Figure 1):

$$S_t = \sqrt{S_x^2 + S_y^2} \quad (3)$$

The transverse sensitivity is usually expressed as a percentage of the main axis sensitivity:

$$Tranverse(\%) = 100 \cdot \frac{S_t}{S_z} \quad (4)$$

Typical values of transverse sensitivity are: less than 2% for piezoelectric quartz accelerometers and less than 5% for piezoceramic accelerometers.

The calibrator described in this paper generates rectilinear acceleration in the x-y plane at a frequency ω_c. The motion is controlled such that acceleration components along the x and y axis are in phase quadrature (shifted in phase by 90 degrees):

$$a_x(t) = X \sin(\omega_c t) \quad (5)$$

$$a_y(t) = Y \cos(\omega_c t) \quad (6)$$

In the general case equations (5) and (6) describe elliptical motion in x-y plane; if X = Y, then a circle is described. In the automated test system, acceleration components a_x and a_y are measured with reference accelerometers. Acceleration magnitude and direction determined at any time *t* is:

$$a_t(t) = \sqrt{a_x^2 + a_y^2} \quad (7)$$

$$\theta(t) = \tan^{-1}\left(\frac{a_y}{a_x}\right) \quad (8)$$

Maximum transverse sensitivity of the sensor under test (SUT) is then determined from the SUT output, $v_o(t)$, and Eq (7):

$$S_t = \max\left(\frac{v_o(t)}{a_t(t)}\right) \quad (9)$$

Eq (9) describes a time domain method for calculating the maximum transverse sensitivity and assumes phase quadrature of the x and y reference accelerometers. Improved signal resolution can be obtained by using Fourier domain signal processing. The improved resolution is especially useful when testing accelerometers with low sensitivity such as shock accelerometers that may have main axis sensitivities as small as 0.05 mV/g.

A digital Fourier transform is applied to the acquired signals. The spectral components of the SUT and x-y reference sensors evaluated at the excitation frequency ω_c are the complex quantities:

$$A_x(j\omega_c) = FFT(a_x(t))_{\omega=\omega_c} \quad (10)$$

$$A_y(j\omega_c) = FFT(a_y(t))_{\omega=\omega_c} \quad (11)$$

$$V_o(j\omega_c) = FFT(v_o(t))_{\omega=\omega_c} \quad (12)$$

The SUT output that is in-phase with the x and the y reference accelerometers is respectively:

$$V_x = \mathrm{Re}\left(V_o \frac{A_x^*}{|A_x|}\right) \quad (13)$$

$$V_y = \mathrm{Re}\left(V_o \frac{A_y^*}{|A_y|}\right) \quad (14)$$

The cross sensitivities in the x and the y directions are:

$$S_x = \frac{V_x}{|A_x|} \quad (15)$$

$$S_y = \frac{V_y}{|A_y|} \quad (16)$$

Given the above cross sensitivities in the x and y directions, the maximum transverse sensitivity magnitude and direction is calculated:

$$S_t = \sqrt{S_x^2 + S_y^2} \quad (17)$$

$$\theta_t = \tan^{-1}\frac{S_y}{S_x} \quad (18)$$

AUTOMATED TRANSVERSE TESTER

The automated transverse test system consists of a resonant beam, x and y reference accelerometers, independent x and y exciters to generate acceleration in the x-y plane, and personal computer based acquisition and control (Figures 2 and 3). The computer acquires the SUT and x and y reference signals. The computer also controls the motion in the x-y plane, generating near circular motion according to equations (5) and (6) with $X = Y$, while maintaining phase quadrature. Transverse sensitivity is calculated from the acquired signals using Eqs. (10) through (18).

The resonant beam was designed to provide rectilinear motion in the x-y plane, with negligible motion in the z direction and minimal rotational acceleration. The measurement error due to rotational acceleration depends on both the accelerometer's rotational sensitivity (which is generally small) and the level of rotational acceleration of the exciter.

An estimated uncertainty was calculated for the automated test system according to procedures described in reference [1]. Influences contributing to the calculated uncertainty include: exciter rotational acceleration, accelerometer sensitivity to rotation, residual z-axis motion, measurement noise, and random testing errors. For sensors with transverse sensitivities ranging from 0% to 5%, an expanded measurement uncertainty of 0.3% (additive) is typical.

ISO 5347-11:1993 [2] describes a standard method for testing of accelerometer transverse sensitivity. The SUT is mounted to a shaker such that the main sensing axis is perpendicular to the shaker motion (Figure 4). Using a special fixture the sensor is rotated about the sensing axis and measurements taken until the direction and magnitude of largest transverse acceleration is found.

To validate the operation of the automated transverse tester, a number of sensors were tested by the method of ISO 5347-11:1993 and with the new system. A random sampling of the test results is given in Table 1. Characteristics of the sensors tested are provided in Table 2. From Table 1 it can be observed that the transverse sensitivities measured by the two methods were found to agree to within the expanded uncertainty of the automated transverse test system (expanded uncertainty = 0.3%).

***Table 1**: Comparison of two methods.*

	Transverse Sensitivity		
Sensor	**ISO 5347 [2]**	**New method**	**Difference**
353B17 S/N C48274	0.9%	1%	+0.1%
353B17 S/N C48286	0.3%	0.4%	+0.1%
353B33 S/N 60048	0.9%	0.8%	-0.1%
353B33 S/N 60047	0.6%	0.5%	+0.1%
353B04 S/N C44363	0.6%	0.7%	+0.1%
353B04 S/N C44364	0.5%	0.4%	-0.1%

***Table 2**: Sensor Characteristics.*

	Sensitivity (mV/g)	Mass (grams)
353B17	10	2.9
353B33	100	27.0
353B04	10	10.5

CONCLUSION

A new automated system for testing of accelerometer transverse sensitivity has been implemented at PCB Piezotronics. Compared to the manual method of testing described in ISO 5347-11:1993, the automated system provides cost-effectiveness, accuracy, and consistency in the production environment. Additionally, the system can measure transverse output of low sensitivity sensors such as shock accelerometers that may have axial sensitivity as low as 0.05 mV/g.

REFERENCES

[1] NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," 1994.

[2] ISO 5347-11:1993. "Methods for the calibration of vibration and shock pick-ups -- Part 11: Testing of transverse vibration sensitivity," 1993

FIGURES

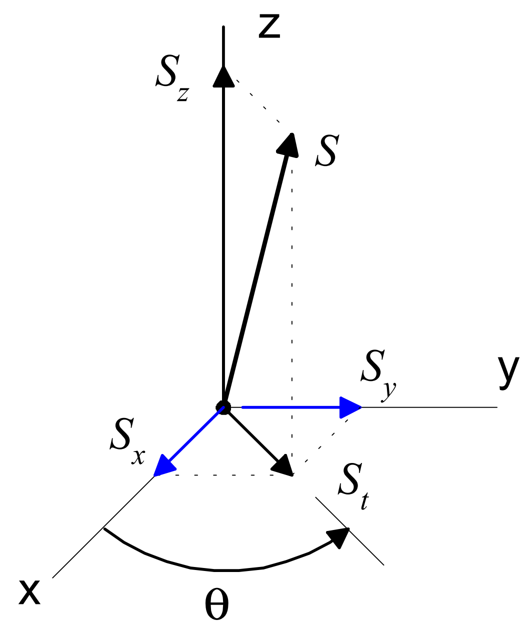

***Figure 1:** Accelerometer sensitivity vector S, and components along x, y, and z axes.*

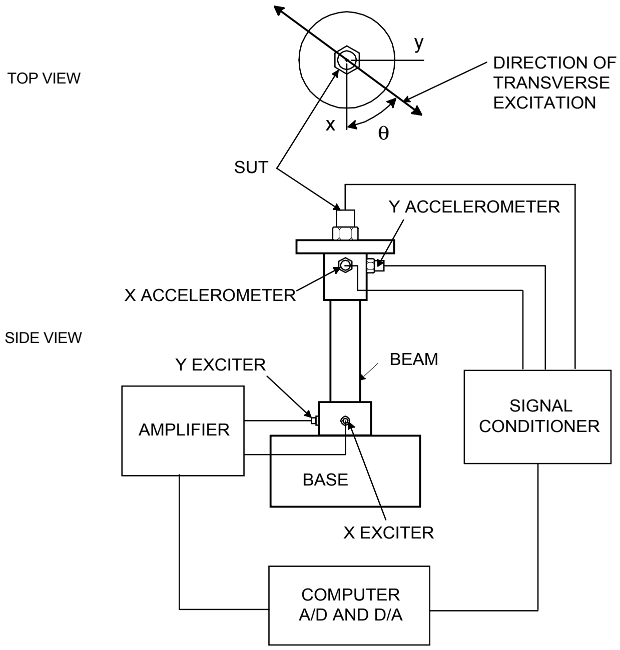

Figure 2: *System for automated testing of accelerometer transverse sensitivity.*

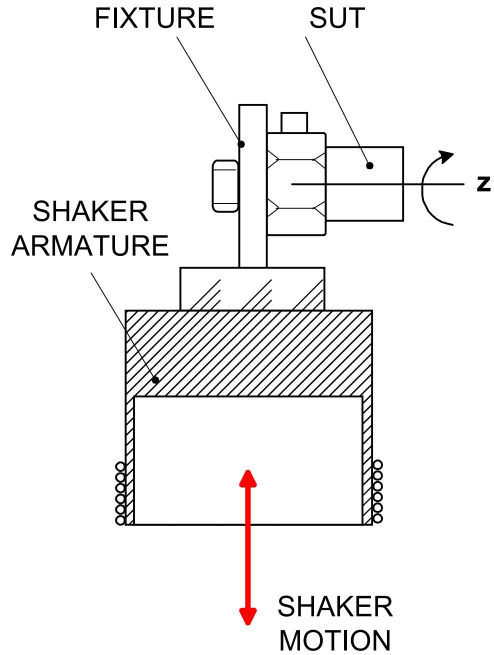

Figure 4: *Method for testing transverse sensitivity using a vibration shaker.*

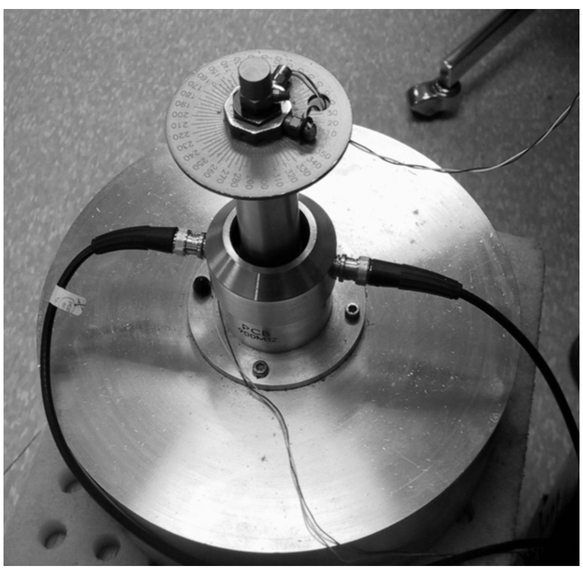

Figure 3: *Resonant beam with reference accelerometers and sensor under test.*