ICP® BASED REFERENCE ACCELEROMETERS

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Abstract: ICP® based accelerometers have become widely used in the field of vibration measurement as general purpose sensors. Charge mode accelerometers have historically been used as the reference for back to back comparison calibrations. This paper introduces the concept that the use of properly constructed ICP® based accelerometers result in a much simpler, more reliable and easier to use calibration system than charge mode accelerometer based systems. Historical data will be provided which documents the long term stability of selected ICP® reference sensors. This paper is relevant to anyone evaluating or assessing both secondary and primary accelerometer calibration system performance.

Keywords: Accelerometer Calibration, ICP®, Charge, Stability, Reference Accelerometer, PCB, Piezotronics

1. INTRODUCTION

ICP® is the registered trademark that is used by PCB Piezotronics, a PCB Group Company to describe a method of powering accelerometers which contain integral microelectronic amplifiers located inside the sensor body itself. Various companies competing in the industry have their own trade-names for the technique, but they all operate off the same principle. The trade names commonly known are IEPE, Deltatron, Piezotron, and so on. This paper will refer to the technique throughout as ICP™ for simplification and brevity purposes. The basic principle[1] is that a power supply unit supplies between 2 and 20 milliamps constant current excitation with an open circuit maximum supply 18-30 volts. Within the accelerometer enclosure itself resides a charge amplifier which is powered by the constant current.

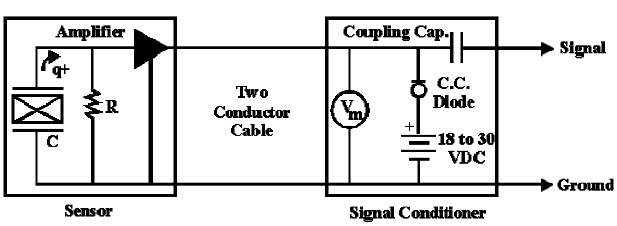

Figure 1 - ICP® system schematic

2. ICP VERSUS CHARGE

It is a well known and understood fact that ICP® based sensor systems provide a more robust accelerometer signal conditioning environment than charge based sensor systems. With ICP® the charge amplifier is located within the hermetically sealed environment of the sensor and thus is protected from most if not all external influences. The signal levels on the instrumentation system level are high level voltage signals as opposed to ultra-low level charge signals.

Key differences between ICP® and Charge systems:

ICP™	Charge
Fixed Sensitivity	Variable
Fixed HP filter	Variable
Fixed LP filter	Variable
No tribo-electric effect	Significant
EMI insensitive	Significant
Humidity insensitive	Significant
Open circuit indication	None
Short circuit indication	None
Inexpensive cond.	Expensive cond.
Minimal thermal	Little thermal

If one examines the above list, it would appear that a charge mode reference sensor is quite the advantage. We can change the sensitivity of the sensor, we can change the filter settings. On the surface this would appear to be quite the advantage until one considers the fact that in a calibration setting you actually do not want to have that flexibilty. Therefore an ICP sensor with it's hermetically sealed fixed gain, fixed filter architecture is actually an advantage.

There are a significant number of advantages to placing the amplifier microelectronics inside the sensor element and hermetically sealing them. Not the least of which is that in addition to being protected from changes in the environment and external influences such a sensor system is inherently capable of being self-diagnosing from the standpoint of detection of cable shorts and opens. Figure 2 below is a graphic example of the signal characteristics of an ICP® sensor system.

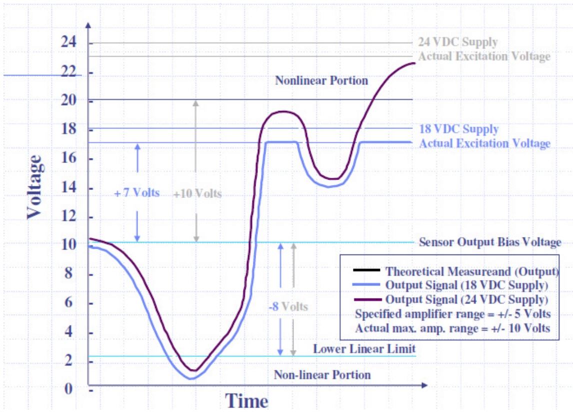

Figure 2 – Typical ICP® signal waveform showing Open / Short, Linearity, Bias, and signal excursion

3. OTHER CHARACTERISTICS OF A GOOD REFERENCE ACCELEROMETER

There are several other characteristics of a good reference accelerometer. A good reference sensor should be quartz based, and of shear construction to eliminate base strain effects. If the sensor is to be used for high frequency calibration work, it should be of integral cable construction so as to eliminate the effect of connector resonance.

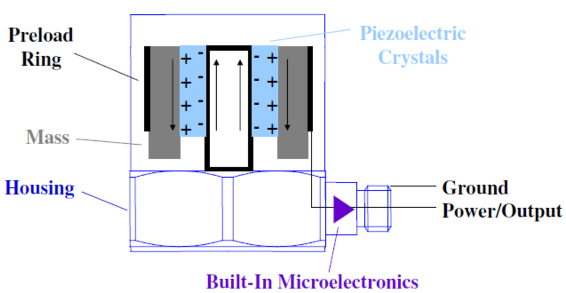

Figure 3 – Quartz Shear construction

4. LONG TERM STABILITY

PCB uses ICP® shear quartz accelerometers in calibration systems as transfer standards, daily verification standards and as back-to-back standards. For these applications, the stability and repeatability of the sensitivity value is of utmost importance. The following is an examination of the change in sensitivity over yearly recalibration cycles.

Fifteen ICP® shear quartz sensors were recalibrated at approximately yearly intervals. Various models were tested having nominal sensitivities of 10 mV/g (X353M295, 353B03, 353B04, 353M319), 20 mV/g (353B01), 100 mV/g (353B33), and 500 mV/g (301M26, Q353B51). The number of recalibrations for each sensor varied from 1 to 11, for a total of 37 recalibrations. The calibrations were performed by laser interferometery using PCB's ISO-16025 accredited primary calibration facility
at a frequency of 100 Hz. At this frequency the measurement uncertainty of sensitivity is equal to 0.2% (k = 2). Theoretically, it should be difficult to resolve a sensor stability that is much lower than the system uncertainty. However, the actual uncertainty and repeatability is much better than 0.2%, allowing resolution of stability trends.

The plot below shows the change in sensitivity (%/year) for all 37 recalibrations. Two standard deviations of the data is equal to 0.11%. This can be interpreted as saying that if 100 sensors were recalibrated at yearly intervals, 95 of sensors would have reported a change in sensitivity less 0.11% upon recalibration.

The average value of the data is equal to -0.02%/year. This says that on average, when an accelerometer is recalibrated at a one year interval, the sensor will have lost a small amount of sensitivity equal to 0.02%.

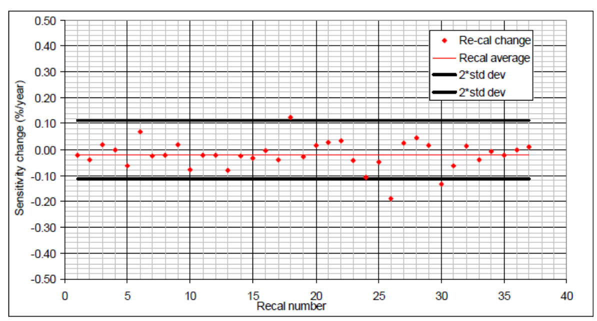

Figure 5 – Stability of 37 calibrations supporting sensitivity change of -0.02% per year

The plot and table below shows trend data for an X353M295 (10 mV/g shear quartz) over an 8 year time interval. During its first year the sensitivity dropped 0.13%. In its second year it dropped 0.06%. In its third and subsequent years there was insignificant change in sensitivity (measurement "noise" of about 0.00%/year and 0.02%/year). This sensor is typical of those sensors that show a significant (>0.1% change) in sensitivity. The change is almost always within the first year after manufacture and the change almost always a decrease in sensitivity. In later years the change in sensitivity is negligible. Also displayed on this plot is primary calibration data obtained from Physikalisch-Technische Bundesanstalt (PTB) in Germany and from the National Institute of Standards and Technology (NIST) in the United States. Each organization's uncertainty (k=2) is displayed with vertical error bars on the data point. The large uncertainty of the NIST calibration (=1%) illustrates the difficulty of resolving drift stability of only a few hundredths of a percent when the measurement system has an uncertainty of 1%.

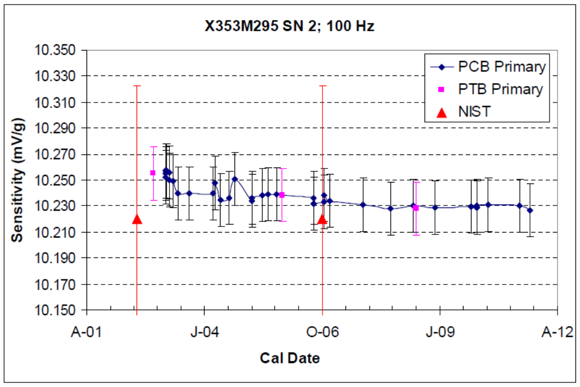

Figure 4 – 8 year history of an ICP® Quartz Sensor

Date	Temp (F)	Sensitivty (mV/g)	Sensitivity change from original (%)	Cal interval years	Sensitivity change (%/year)
2/19/2003	70	10.255	0.00		
3/25/2004	72	10.240	-0.15	1.10	-0.13
2/21/2005	69	10.234	-0.20	0.91	-0.06
7/31/2006	70	10.236	-0.19	1.44	0.01
9/21/2007	69	10.231	-0.23	1.14	-0.04
11/21/2008	71	10.230	-0.24	1.17	-0.01
5/27/2009	72	10.229	-0.25	0.51	-0.02
5/20/2010	70	10.229	-0.25	0.98	0.00
5/18/2011	71	10.230	-0.24	0.99	0.01

Figure 5 – Sensitivity change of X353M295

7. SPECIFIC SENSOR RECOMMENDATIONS

PCB and The Modal Shop have configured a specific set of reference, verification and transfer standard sensors which are supplied with our calibration systems. These sensors are Double-ended(DE) and Single-ended(SE) in element configuration. A complete list of kitted sensors and their descriptions may be found on The Modal Shop website at www.modalshop.com . The kits are complete, in that they include the sensor, cabling, a signal conditioner and appropriate accredited primary calibration.

Description	***Kit Model***	***PCB Model***
DE B2B	9106C01	301A10
DE B2B shock	9106C31	301A12
SE Primary Gold Std	9105C11	353M319
SE Verification	9105C01	353B03
SE Low Frequency	9105C21	Q353B51
SE Verification shock	9105C31	350A13
DE B2B low frequency	9106C21	301M26
DE B2B Be ABS insert	9106C11	080Axxx

Figure 6 – ICP® Calibration Sensor recommendations

8. CALIBRATION OF AN ICP SIGNAL CONDITIONER

For years the industry has grown accustomed to calibrating charge mode signal conditioners by coupling a voltage waveform into the signal conditioner front end through a precision capacitor, thus simulating a charge mode sensor. Calibration of an ICP® signal conditioner is not much more complicated. In order to calibrate an ICP® signal conditioner, an accelerometer simulator needs to be utilized. One such accelerometer simulator is the PCB 401B04 sensor simulator. The simulator is then driven with a swept sine, just as one would drive the coupling capacitor of a charge amplifier. An FFT (or DFT) analyser is then utilized to measure the transfer function of the ICP® amplifier itself. Electrically speaking, the PCB 401B04 is nothing more than a voltage follower.

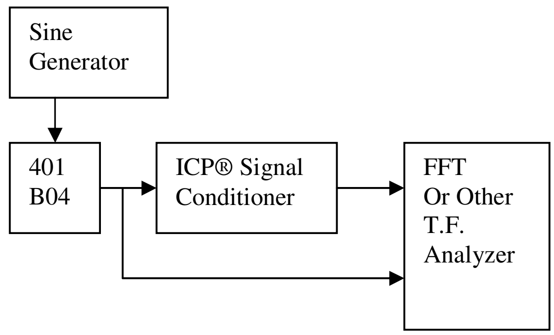

Figure 7 – Calibration of an ICP® signal conditioner

9. ICP® SENSOR THERMAL CHARACTERISTICS

Quartz ICP sensors do exhibit a minor thermal sensitivity. This thermal sensitivity is quite small over the operational temperature range of calibration laboratories as specified by ISO 16063-21 [2] and 16063-22 [3]. A plot of thermal sensitivity is shown in Figure 8 below.

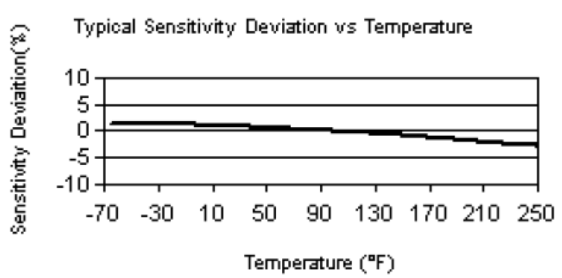

Figure 8 – Typical thermal sensitivity of a Quartz ICP® accelerometer

10. ICP® SENSOR SENSITIVITY AS A FUNCTION OF ICP® CURRENT

As specified by ISO 16063-21 [2] and 16063-22 [3] the reference sensor and it's signal conditioning should be calibrated as a pair. Thus in general, one can say that the amount of current supplied to an ICP® reference sensor is not a factor. That being said, there is what appears to be a slight sensitivity shift to an ICP® sensor as a function of excitation current. This is an area of current work of the author to understand where this effect comes from. It should be noted that under the general circumstance of a calibration laboratory, one tends to run the ICP® sensor at a value of 4ma ±0.1 ma, and thus the shift is negligible.

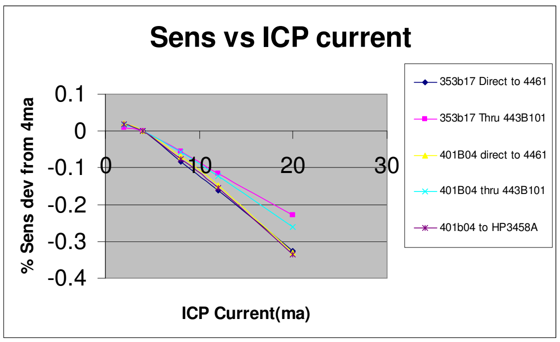

Figure 9 – Sensitivity of several sensors and simulators as a function of ICP® supply current.

11. REFERENCES

[1] http://www.pcb.com/techsupport/tech_signal.php

[2] ISO16063-21 [2003] Methods for the calibration of vibration and shock transducers, Part 21 – Vibration calibration by comparison to a reference transducer

[3] ISO16063-22 Methods for the calibration of vibration and shock transducers, Part 22 – Shock calibration by comparison to a reference transducer