VIBRATION TESTING OF MINIATURE S-BEAM (LSB200) & MINIATURE BEAM LOAD CELL (LSM400)



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Executive Summary

During this past year FUTEK Advanced Sensor Technology, located in Irvine California, found itself faced with yet another unique challenge from a client requiring a specialized sensor. This new challenge would not only require the sensors in question to endure the usual environmental hazards of high/low temperature and moisture, but also survive vibration testing to a controlled industry vibration standard by an independent testing lab. What follows is a chronological account of the preparation, testing and an analysis of the required vibration testing.



On May 2, 2008, FUTEK Advanced Sensor Technology vibration tested two LSB200, and two LSM400 sensors, while mounted, and operating in a clients application. The Power Spectral Density (PSD) maintained during the testing was 0.01g²/Hz over a frequency range of 20 – 2000 Hz as defined in MIL-STD-810E. Power Spectral Density is a positive real function of a frequency variable related to a stationary stochastic process (non-predictable, random process), or a deterministic (predictable) function of time. The units of measure are power per Hz, or energy per Hz, in this case, the established value of gravity "g" (energy) is used to describe the amount of energy per Hz (width). In general, this is referred to as the Spectrum of the signal, in this case, a wave vibration intensity captured during testing by accelerometers. After verifying their credentials, the testing was contracted out to National Technical Services (NTS). NTS tested the units to the defined standard and maintained test integrity, serviceability of testing equipment, and data capture of the accelerometers. Test data is available upon request. A FUTEK Engineer designed and machined all other testing components and tooling needed for the project. The client's test application was operated during the testing by a FUTEK engineer who was responsible for capturing data from each set of units during testing.

The objective was to vibration test to establish survivability and validation of two LSB200 5 lb and two LSM400 5 lb, see figures 4 and 5, while mounted and operating in the test application. Testing was done per MIL STD-810E, with a ten-minute interval in each directional axis x, y, z, for each set of units. A PSD of $0.01g^2$ /Hz was maintained during the test intervals of ten minutes per axis per set of sensors.

The contract services of NTS, located in Fullerton California, were used for the testing of the FUTEK units while a FUTEK Engineer ran the clients test Module, capturing data from each sensor during each of the ten-minute intervals at a collection rate of one reading per second, for validation of the units. Comparison of before and after vibration testing calibration results were analyzed to see any significant change in, output signal, nonlinearity, or zero balance. The results of the comparison for both before and after calibration results are shown in figures 7 through 23.

A FUTEK Engineer designed and machined the required tooling in-house. This consisted of a one-inch thick aluminum (6061-T6) plate, twenty-four inches square. The plate was drill/milled to a set bolt pattern that would secure the test application to the plate and in turn secure both to the C-10 vibration-testing table see figure 1, 2 and 3. The test application was secured to PDT00473, Vibration-mounting plate, with four ¼-20 machine cap screws. Two additional points were used for both alignment and mounting, these were the client's spring loaded M6X1 mounting screws locate on the test application, see figure 3. The assembly was then mounted to the NTS C-10 Vibration tester using the 2 X 2 X 3/8 holes pattern, see figure 6. NTS monitored the tests using two accelerometers one oriented in each axis, see figure 6. This set up was repeated for each 10 minute test in each directional axis. During the test runs, data was captured from each sensor insuring the sensor did not fail to produce a signal or fault out during vibration testing. NTS provided test data showing the PSD of 0.01g²/hz was maintained during the test-ing periods.



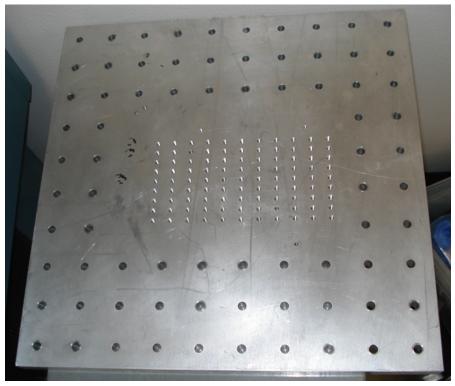


Figure 1, PDT00473 mount plate for vibration testing.



Figure 2, Low Pressure slip table, capable of vibration testing in the x, y, and z-axis.



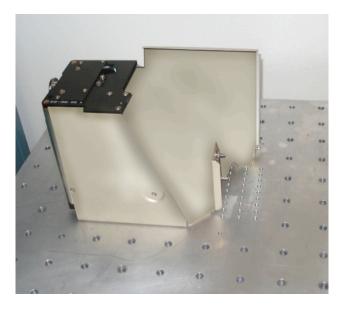


Figure 3, PDT00473 with Client's Module in place; note, unit shown is not bolted down.



Figure 4, LSB200



Figure 5, LSM400



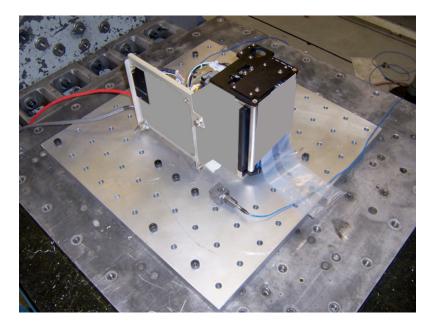


Figure 6, Module shown mounted to the C-10 vibration table oriented in the X-axis.

Of the four FUTEK units tested, none failed during testing, came loose, or had any interruption in signal. Data capture rate was 1/sec as per application software. The plots generated are for comparison to a standard not provided by the client. To better show and validate the robust nature of the units, before and after calibration results were generated which show virtually no change in calibration output signal, nonlinearity, or zero balance, see figure 5 through 12. Further examination of the internal sections show no visible damage, loose or potential disconnects. All adhesives used in the fabrication of the units showed no sign of failure either. Cover screws installed with Loctite 262 held and showed no sign of fatigue or failure. The adapters installed on the LSB200 with Loctite 242 showed no sign of failure either. Cable connections and cable strain relief's were examined and showed no sign of fatigue or potential for failure. It is clear that these two sets of units, LSB200 and LSM400, survived this series of vibration tests. Therefore, it is reasonable to expect these units to survive an environment which could potentially expose them to a vibration Spectral Density of $0.01g^2/Hz$.



Calibration						
Print Exit						
Main Data	Electrical Data	- Load Data				
Test ID 52322		Load lb	Output mV/V	Non-Lin %RO	Hys %R0	CE %R0
Sensor ID 243738	Excitation 5.000 VDC	0				
	Rin 351.71 Ohms	1	-0.4023			
Calibration Time 2:06:08 PM	Rout 352.74 Ohms	2				
Calibration Date 11/19/2007		3				- C
Tech ID Angel Mendoz	Leakage Pass	4	-1.6081	-0.015		-
		0				-
Humidity 59.4	Test Results		0.0002			100
Temperature 72.9	Non-Lin -0.015 %R0					
Channels 1	Hys %R0					
Load Direction Compressio -	CE %R0	•				
Comments	First Zero -0.0266 mV/V					
	Second Zero -0.0259 mV/V	Creep				
		Test Load		Interval	Min.	
	Zero Ret -0.011 %R0	Test Time	Min.	Creep Err	or 280	
C PreCheck G Full Test	Full Scale -2.0105 mV/V		1	Croop En		
Instruments Used	Non-Rep 🎗					
	Shunts		1.0			
	Shunt (KOhr Output mV/V					
Model	60 1.4560					
ID						
CalFactor						
,						
Disp High						
Input High						

Figure 7, Sensor ID: 243738, LSB200, Calibration results performed on 11/19/2007, before vibration testing, prior to span resistance.

rint Exit							
Main Data	Electrical Dat	ta	Load Data				
Test ID 57886			Load b	Output mV/V	Non-Lin %R0	Hys %R0	CE %R0
Sensor ID 243738	Excitation	5.002 VDC	0				0.0
and the factor of	Bin	463.64 Ohms	1	-0.3052		0.058	-0.0
Calibration Time 1:28:27 PM		352.24 Ohms	2				-0.0
Calibration Date 5/9/2008			3				-0.0
,	Leakage	Pass	4	-1.2219			0.0
Tech ID Victor Garcilaz			5				0.0
Humidity 47.2	- Test Besults		4	-1.2224			0.0
Temperature 71.6		-0.025 %R0	2				0.0
			1	-0.6114			0.0
Channels 1	Hys	0.058 %R0	0				0.0
Load Direction Compressio -	CE	0.037 %R0	1	0.000			•
Comments	First Zero	-0.0213 mV/V					-
	Second Zero	-0.0215 mV/V	Creep				
		0.027 %R0	Test Load	5	Interval 1	Min.	
			Test Time	10 Min.	Creep Er	ror %RD 0.026	*
C PreCheck @ Full Test	Full Scale	-1.5274 mV/V					
Instruments Used	Non-Rep	*	Time Ib		V/V Error %R0		^
			1:30:4		1.5266		
	Shunts		1:31:4			0.026	
Model			1:32:5			0.013	
			1:34:5			0.020	
ID			1:35:5			0.013	
CalFactor			1:36.5			0.007	
			1:37:5			0.013	
			1:38.5	6 PM -1	.5263 .	0.020	
Disp High							•

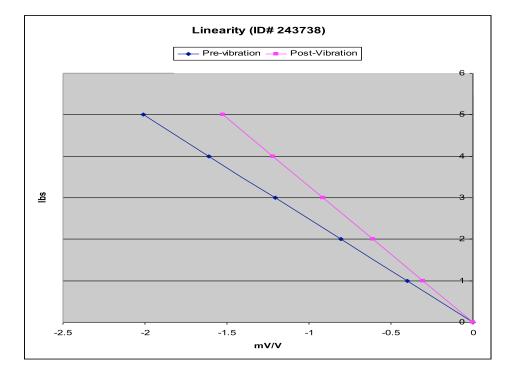
Figure 8, Sensor ID: 243738, LSB200, Calibration results performed on 5/19/2007, after vibration testing, with span resistor.

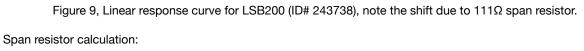
% Zero balance shift calculation:

$$\left(\frac{Zero_{pre-vib} - Zero_{Post-vib}}{Output_{Max}}\right) \times 100 = xx\%$$



$$\left(\frac{0.0259 - 0.0213}{1.5274}\right) \times 100 = 0.3012\%$$





$$\left(\frac{\left(R_{B}\times V_{o}\right)-\left(V_{spo}\times R_{B}\right)}{V_{spo}}\right)=R_{span}$$

$$\left(\frac{\left(51.71\Omega \times 2.0105 \frac{mV}{V}\right) - \left(1.5274 \frac{mV}{V} \times 351.71\Omega\right)}{1.5274 \frac{mV}{V}}\right) = 111.2420\Omega$$

Pre-vibration rated output calculation with 111Ω resistor:

$$\frac{352\Omega}{(352\Omega+111\Omega)} \times 2.0105 \, {}^{mV}\!/_{V} = 1.5285 \, {}^{mV}\!/_{V}$$

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Output shift error:

$$\frac{\left(1.5285 \frac{mV}{V} - 1.5274 \frac{mV}{V}\right)}{1.5274 \frac{mV}{V}} \times 100 = 0.072\%$$

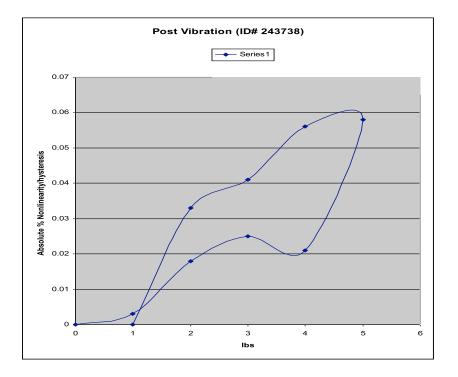


Figure 10, Post vibration % Nonlinearity and Hysteresis.



int Exit						
Main Data	Electrical Data	Load Data				
Test ID 53216		Load b	Output mV/V	Non-Lin %R0	Hys %RO	CE %R0
Sensor ID 243737	Excitation 5.010 VDC	0	0.0000	0.000		
	Bin 471.57 Ohms	1	-0.3009	0.016		
Calibration Time 7:02:44 AM		2	-0.6016			
Calibration Date 12/19/2007	Rout 352.58 Ohms	3	-0.9022			
	Leakage Pass	4	-1.2027			
Tech ID Rogelio Camp		5	-1.5031	0.000		
Humidity 50.8	Test Results	0	0.0002			_
Temperature 73.8	Non-Lin 0.028 %R0					
Channels 1	Hys %R0					
Load Direction Compressio -	CE %R0	•				
Comments	First Zero -0.0142 mV/V	•				
Comments		Creep				
	Second Zero -0.0137 mV/V	Test Load		Interval	Min	
				THOUSE AND A	MIN.	
	Zero Bet -0.012 %R0	rest Lodu				
	Zero Ret -0.012 %R0	Test Time	Min.	Creep Err	ror %R0	
C PreCheck C Full Test	Zero Ret 0.012 %R0 Full Scale 1.5031 mV/V		Min.	Creep Er	ror %R0	
C PreCheck Full Test Instruments Used			Min.	Creep En	ror %R0	
	Full Scale -1.5031 mV/V Non-Rep 🛪		Min	Creep En	ror %R0	
	Full Scale -1.5031 mV/V Non-Rep %		Min	Creep En	ror %R0	
Instruments Used	Full Scale -1.5031 mV/V Non-Rep % Shunts Shunt (KOhn Output mV/V)		Min	Creep En	ror %R0	
Instruments Used Model	Full Scale -1.5031 mV/V Non-Rep %		Min	Creep En	ror %R0	
Instruments Used	Full Scale -1.5031 mV/V Non-Rep % Shunts Shunt (KOhn Output mV/V)		Min	Creep En	ror %R0	
Instruments Used Model ID	Full Scale -1.5031 mV/V Non-Rep % Shunts Shunt (KOhn Output mV/V)		Min	Creep En	ror %R0	l
Instruments Used Model	Full Scale -1.5031 mV/V Non-Rep % Shunts Shunt (KOhn Output mV/V)		Min	Creep Err	tor %R0	l

Figure 11, Sensor ID: 243737, LSB200, Calibration results performed on 12/19/2007, before vibration testing.

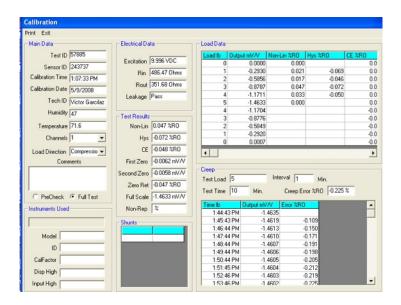


Figure 12, Sensor ID: 243737, LSB200, Calibration results performed on 5/9/2008, after vibration testing.

% Zero shift calculation:

$$\left(\frac{0.0142 - 0.0062}{1.4633}\right) \times 100 = 0.5467\%$$



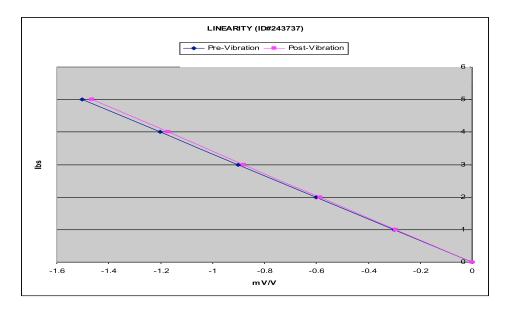


Figure 13, Linear response curve for ID# 243737; note, span resistor installed prior to pre-vibration testing.

Span resistor calculation:

$$\left(\frac{\left(471.57\Omega \times 1.5031^{mV}/_{V}\right) - \left(1.4633^{mV}/_{V} \times 471.57\Omega\right)}{1.4633^{mV}/_{V}}\right) = 12.8213\Omega \approx 13\Omega$$

Pre-vibration rated output calculation with 111Ω resistor:

$$\frac{471.57\Omega}{(471.57\Omega+13\Omega)} \times 1.5031^{mV} / V = 1.4677^{mV} / V$$

Output shift error:

$$\frac{\left(1.5628 \frac{mV}{V} - 1.4633 \frac{mV}{V}\right)}{1.4633 \frac{mV}{V}} \times 100 = 0.034\%$$



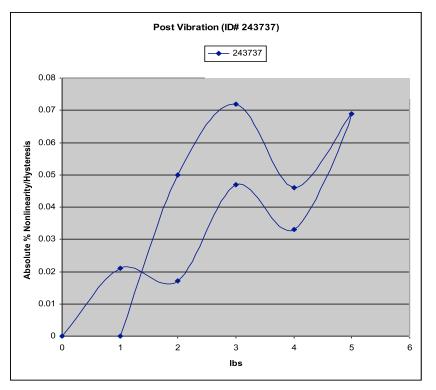


Figure 14, Post vibration Absolute % Nonlinearity/Hysteresis.

nt Exit fain Data	Electrical Da		- Load Data				
	Electrical Da	ala	Load Data				
Test ID 57086			Load g			Hys %RO	CE %R0
Sensor ID 255441	Excitation	9.995 VDC	0				
	Bin	415.17 Ohms	50				1
Calibration Time 7:59:04 AM	Band	351.76 Ohms	100				_
Calibration Date 4/23/2008			150				-
Tech ID Angel Mendoz	Leakage	Pass	200				_
			250				
Humidity 46.8	- Test Besult:		300		0.000		
Temperature 72.3	Non-Lin	0.015 %R0		0.0001			
Channels 1		%R0					
Load Direction Tension V	CE						
Comments	First Zero	-0.0172 mV/V	•				
Connerna			Creep				
	Second Zero	-0.0169 mV/V	Test Load		Interval	Min.	
	Zero Ref	0.027 %R0					
C PreCheck @ Full Test	Full Scale	0.3489 mV/V	Test Time	Min.	Creep Er	ror %R0	
nstruments Used	Non-Rep	2					
	Shunts			-			
		WV/Vm turqtuO					
Model	3						
ID							
CalFactor							
Disp High							

Figure 15, Sensor ID: 255441, LSM400, Calibration results on 4/23/2008, before vibration testing.



Main Data	Electrical Da	ta	Load Data					
Test ID 57884			Load g	Output mV/V	Non-Lin %R0	Hys %R0	CE %R0	
Sensor ID 255441	Excitation	9.995 VDC	0	0.000	0.000			1
	Bin	415.37 Ohms	50					1
Calibration Time 11:51:40 AM		351.64 Ohms	100					5
Calibration Date 5/9/2008			150					
,	Leakage	Pass	200					
Tech ID Victor Garcilaz			250					
Humidity 48	- Test Results		300					
Temperature 72.3		-0.009 %R0	250					
			150					
Channels 1	Hys	-0.017 %R0	100					
Load Direction Compressio -	CE	-0.049 %R0	1	0.050				ŕ
Comments	First Zero	-0.0136 mV/V					-	<u>_</u>
	Second Zero	V.Vm 0000.0	Creep	200	Interval 1			
	Zero Bet	-0.049 %R0	Test Load	1300	-	Min.		
			Test Time	10 Min.	Creep Er	ror %R0 0.029 3	*	
PreCheck C Full Test	Full Scale	-0.3492 mV/V	-	10			-	_
Instruments Used	Non-Rep	*	Time g 11:55:4	Output m	V/V Error %R0 0.3492			*
			11:56:4			0.000		-
	Shunts		11:57:4			0.029		
Model			11:58.4			0.000		
			11:59.4			0.029		
ID			12:00.4			0.000		
CalFactor			12:01:4	7 PM -	0.3493	0.029		
Dis Mith			12:02:4	8 PM -	0.3493	0.029		
Disp High			12:03:4	9 PM 4	0.3493	0.029		
Input High			12:04:4	0 DM	1 3493	0.029		•

Figure 16, Sensor ID: 255441, LSM400, Calibration results on 5/9/2008, after vibration testing.

% Zero shift calculation:

$$\left(\frac{0.0172 - 0.0136}{0.3492}\right) \times 100 = 1.0309\%$$

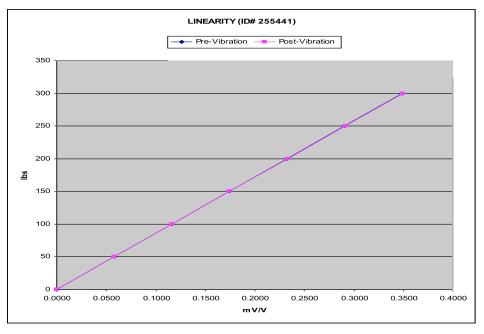


Figure 17, Linearity response curve for ID# 255441.



Output shift error:

$$\frac{\left(0.3489\,^{mV}/_V - 0.3492\,^{mV}/_V\right)}{0.3492\,^{mV}/_V} \times 100 = 0.086\%$$

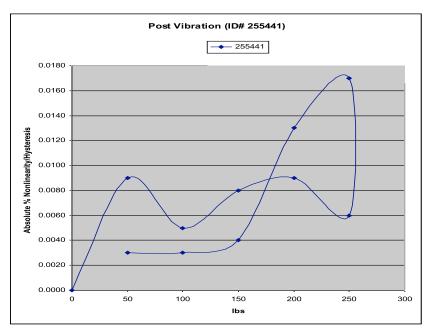


Figure 18, Post vibration Absolute % Nonlinearity/Hysteresis.

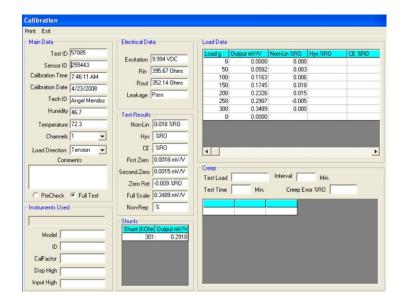


Figure 19, Sensor ID: 255443, LSM400, Calibration results on 4/23/2008, before vibration testing.



rint Exit							
Main Data	Electrical Da	ta	- Load Data				
Test ID 57882		<u></u> 2	Load g	Output mV/V	Non-Lin %R0	Hys %R0	CE %R0
Sensor ID 255443	Excitation	9.994 VDC	0	0.0000	0.000		
	Bin	396.80 Ohms	50	-0.0583	-0.001	0.015	
Calibration Time 11:22:59 AM			100	-0.1165		0.020	
Calibration Date 5/9/2008	Rout	352.00 Ohms	150	-0.1748	0.015		
	Leakage	Pass	200	-0.2331	0.010	0.011	
Tech ID Victor Garcilaz	1.000000000		250	+0.2913		0.010	
Humidity 48	- Test Besults		300	-0.3496	0.000		
1.0			250	-0.2913			
Temperature 72.3	Non-Lin	0.015 %R0	200	-0.2331			
Channels 1	Hue	0.020 %R0	150	-0.1748			
			100	-0.1166			
Load Direction Compressio -	CE	0.021 %R0	< 1 ⁵⁰	0.0500			•
Comments	First Zero	-0.0655 mV/V					
		0.0070.1/11	Creep				
		-0.0670 mV/V	Test Load	300	Interval 1	Min.	
	Zero Ret	0.005 %R0			1.		
PreCheck C Full Test	E. H.C	-0.3496 mV/V	Test Time	10 Min.	Creep Err	or %R0 0.029 \$	8
			Time g	Output mV	V Error %R0		
nstruments Used	Non-Rep	1.4	11:38:4		3494		
	Shunts		11:39:4	7 AM -0	3495	0.029	
	Shurks		11:40:4	8 AM -0	3494	0.000	
Model			11:41:4	8 AM -0.	3495	0.029	
ID			11:42:4	0- MA 8	3495	0.029	
10			11:43:5	0- MA 0	3494	0.000	
CalFactor			11:44:5	1 AM -0.	3495	0.029	
Diss High			11:45:5	2 AM -0.	3495 (0.029	
Disp High			11:46:5	3 AM -0.		0.029	
Input High			11:47:5		3495	1 029	

Figure 20, Sensor ID: 255443, LSM400, Calibration results on 4/23/2008, after vibration testing.

% Zero shift calculation:

$$\left(\frac{0.0142 - 0.0062}{0.3496}\right) \times 100 = 2.2883\%$$

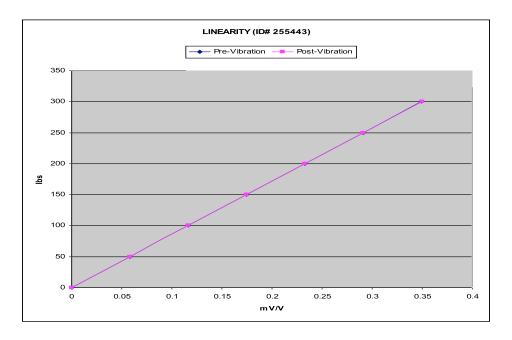


Figure 21, Linearity response curve for ID# 255443.

Output shift error:

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$$\frac{\left(0.3498 \frac{mV}{V} - 0.3496 \frac{mV}{V}\right)}{0.3496 \frac{mV}{V}} \times 100 = 0.057\%$$

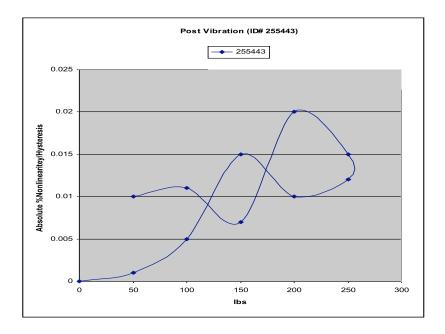
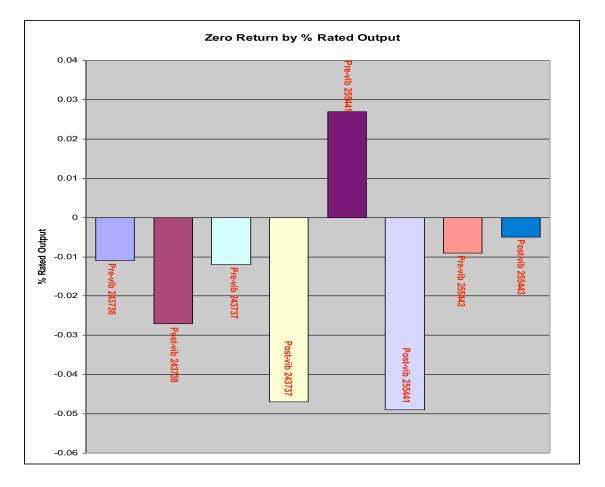
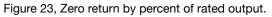


Figure 22, Post vibration Absolute % Nonlinearity/Hysteresis.







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