Smart Diagnostics® Application Note

Vibration Sensor Performance

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KCF Technologies, Inc.

Overview

KCF's SmartDiagnostics® Vibration Sensor Node (SD-VSN-2) is designed to provide broadband acceleration data on a miniscule power budget, allowing accurate wireless data collection with an extremely long battery life. Taking advantage of MEMs technology and circuit design expertise, the Vibration Sensor Node is capable of reproducing the function of a traditional piezoelectric wired accelerometer in a more convenient package which can be deployed and managed much more easily than wired sensors. This document describes the vibration sensor performance.

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Give Your Machines a Voice

Introduction

The SmartDiagnostics® wireless vibration sensor accurately measures vibration, mainly for machine health analysis. This type of analysis is performed on machines such as pumps, motors, gearboxes, etc. As these types of machines degrade, they begin to exhibit vibration symptoms that can be used to identify, classify, and diagnose various types of faults. This information is then used by maintenance and reliability personnel to perform specific and planned repairs.

Since most vibration is periodic, it is generally characterized by cyclic motion at a given repetition or frequency. Vibration excitations from different sources like gears meshing or shaft imbalance add together linearly. These components can be separated and quantified using frequency spectrum analysis, which shows the relative amplitude of vibration contributions versus their frequency.

Most machine vibration health symptoms occur in the 0-4 kHz frequency range which the SmartDiagnostics® sensor is designed to measure. These vibrations occur over an acceleration amplitude range that varies between a few milli-g up to as much as 16 g.

Image scaled to actual size

This document describes the vibration characteristics of the SmartDiagnostics® vibration sensor in terms of its frequency and amplitude performance. The following sensor characteristics are for the entire wireless vibration sensor rather than the MEMS accelerometer chip alone. This is important because the sensor housing, chip mounting method, and electronic implementation strongly influence the net vibration measurement accuracy. For example, resonance of the plastic housing or circuit board on which the chip mounts often causes significant gain or loss in the sensor amplitude at specific frequencies, which in turn contaminate the sensor output and give misleading machine health results. The SmartDiagnostics® sensor is carefully designed to eliminate such problems.

Filter Design

The SmartDiagnostics® wireless vibration sensor circuit contains a 3rd-order Sallen-Key low-pass filter which eliminates high-frequency noise from the sensor measurement. This ensures that high-frequency vibration or noise above the measurement frequency of the accelerometer does not cause aliasing or corruption of the vibration data within the measureable frequency range. The filter gain in the 2-4 kHz region compensates for a small amount of transducer frequency dependent sensitivity, giving a nearly flat frequency response as is shown in the Sensor Performance Plot. Owing to the transducer resonance frequency, which occurs in the 5-6 kHz range, and the 4 kHz analog filter cut-off, measurements that rely on accurate phase information should be limited to the 0-2 kHz range as a general rule of thumb.

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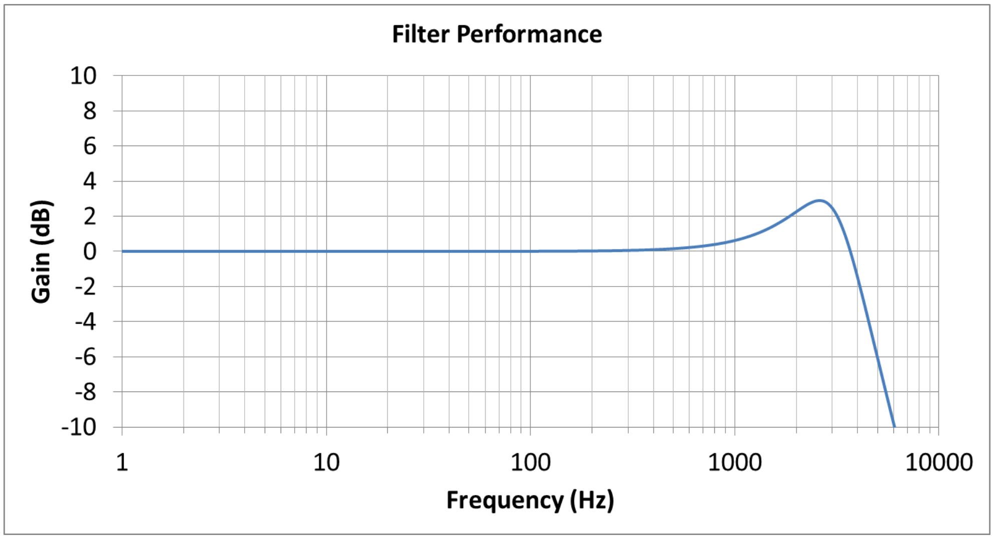

Frequency Response

The primary axis of measurement for the SmartDiagnostics® vibration sensor is along its axis of symmetry, which is perpendicular to the mounting surface. The SmartDiagnostics® axis convention assigns the Y-axis to this primary measurement direction.

The following sensor characteristics were measured using the stud mounted configuration, a precision accelerometer calibration shaker, and a wired piezoelectric reference accelerometer. The characteristics of the Y-axis are shown in the following plot. Considering a Gaussian distribution for the native sensitivity, 99% of the sensors are expected to have a response that falls within +/- 3dB of the truth (reference piezoelectric sensor) over the 0-3.5 kHz range. The X-axis shows a similar response with the exception of the transverse sensitivity which is broken out separately in the following plots.

The frequency response plot was generated from measuring a representative set of 24 SmartDiagnostics® vibration sensors. The combination of the high performance analog accelerometer and a precision matched filter circuit described above produce a response curve that is flat, accurate vibration measurements across the entire 0-4 kHz frequency range, and allow straightforward calibration.

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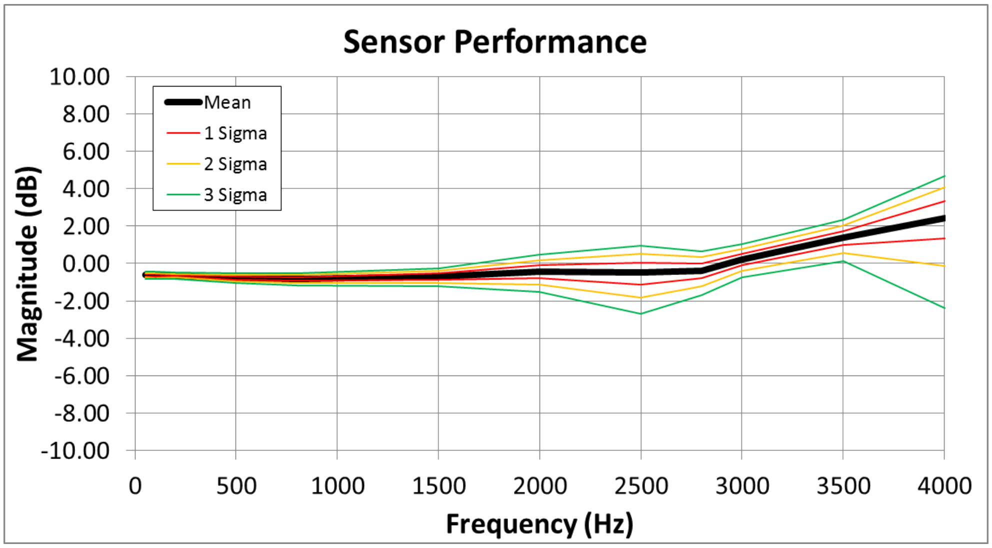
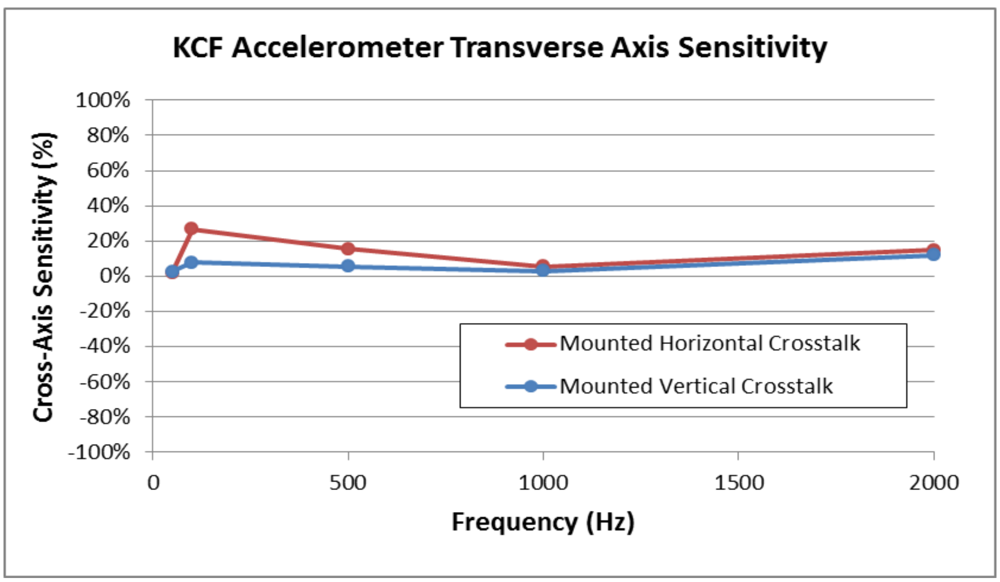


Transverse Sensitivity

The SmartDiagnostics® vibration sensor measures multiple orthogonal axes of vibration in a single sensor package. Accurately measuring vibration in each individual direction is important in vibration analysis, especially when the relative phase of orthogonal vibration (perpendicular) directions is considered. If the sensor is not properly designed, vibration in, for example, a transverse direction to the axis of the sensor stud mount can cause the sensor to rock or flex, which in turn leads to inaccurate measurements. The SmartDiagnostics® sensor has a low center of mass, is low profile, and the sensor transducer is isolated from the battery housing, which lead to very little transverse axis sensitivity. The typical transverse sensitivity for a typical installation is less than 10% as shown in the following figure.



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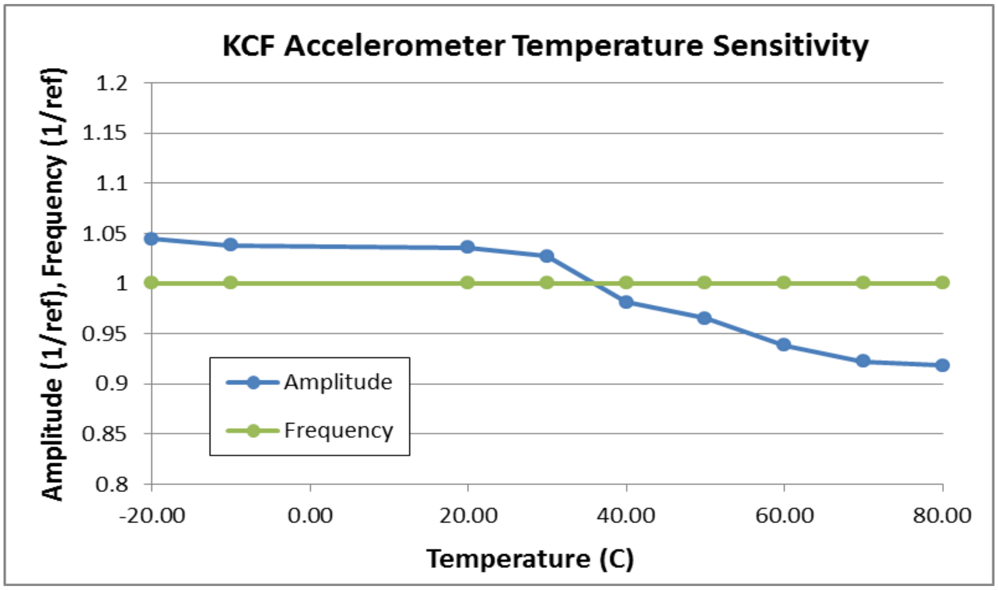
Temperature Sensitivity

Most machine monitoring applications exhibit variable temperature due to weather variation over a calendar year or during machine start up and cool down. The SmartDiagnostics® vibration sensor is designed to eliminate temperature-dependent vibration sensitivity. The following plot shows the amplitude and frequency sensitivity of the sensor across the -20-80 deg. C temperature range.



Sampling Duration and Frequency Resolution

The vibration sensor acquires a group of data points over a given time period and at a given sampling rate. The number of data points per sample set is fixed at 1650, so the number of lines of resolution in a frequency spectrum is fixed at 825. However, to accommodate different machine characteristics, the frequency resolution of a sample set can be adjusted. In this case, increases in frequency resolution are traded for decreases in frequency range. The sampling conditions that SmartDiagnostics® supports is shown in the following table.

Accelerometer Sampling		
Sampling Frequency (Hz)	Sample Duration (s)	Spectral Resolution (Hz)
8192	0.2	5.0
4096	0.4	2.5
2048	0.8	1.24
1024	1.6	0.62
512	3.2	0.31
256	6.4	0.16
128	13	0.08
64	26	0.04

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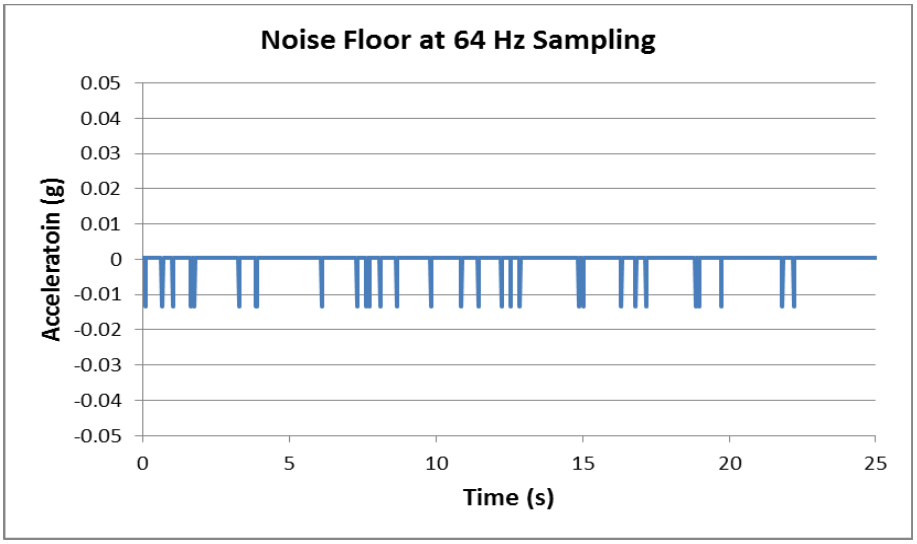
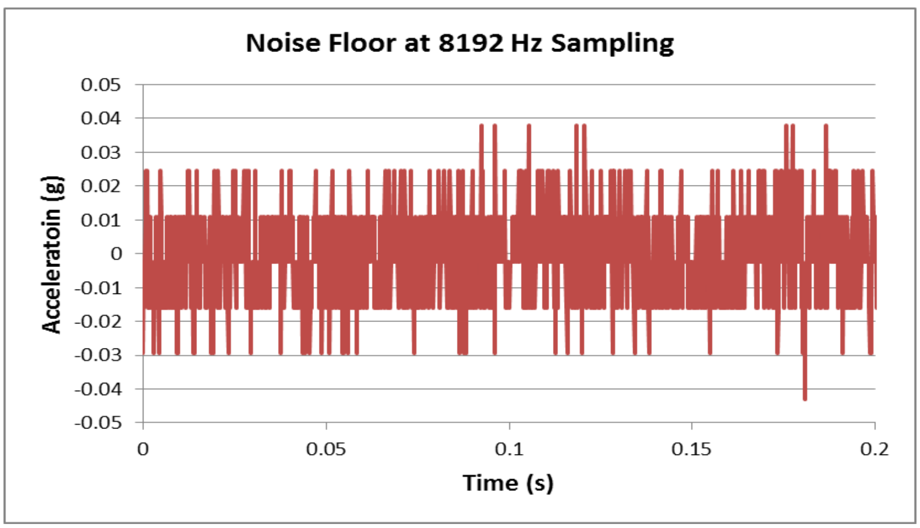
Amplitude Noise Floor, Range, and Resolution

A digital decimation filter is used to down sample from 8192 kHz and therefore enable longer sampling time periods and lower frequency resolution, considering the fixed sample length. The digital filter also reduces the amplitude noise floor of the sensor as is shown in the following figures. The noise floor is as little as ~3 mg RMS at a sampling frequency of 64 Hz and as much as ~19 mg RMS at 8192 Hz. The sensor resolution is 13 mg, which is close to that of the noise floor, giving a discrete noise response.

The lower noise floor at lower frequencies shown in the upper plot is valuable for monitoring large machines, which generally have low characteristic frequencies.





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Velocity Calculation

The SmartDiagnostics® vibration sensor measures acceleration. In many vibration monitoring applications, velocity is used to evaluate machine health. Velocity is calculated by integrating the acceleration signal. The SmartDiagnostics® vibration sensor is unique compared to traditional vibration sensors because it uses a MEMS transducer rather than a piezoelectric transducer. The piezoelectric transducer inherently drifts to a zero value and therefore doesn't measure static acceleration such as gravity. The benefit of this in practice is that it provides high pass filtering of the acceleration data which allows accurate and straightforward integration to determine velocity.

SmartDiagnostics® vibration sensors' static acceleration measurement allows the sensor orientation to be observed in the acceleration signal. The drawback is that the static acceleration values are integrated while calculating velocity. Any small errors in the acceleration static signal lead to drift of the velocity signal. To compensate for this, high pass filter is used to remove this error for calculating velocity.

This high pass filter will diminish frequency content below 0.25% of the sampling frequency. The velocity high pass frequency cutoff is as follows.

Sampling Frequency (Hz)	Frequency Cutoff (Hz)
8192	19.9
4096	9.9
2048	5.0
1024	2.5
512	1.2
256	0.6
128	0.3
64	0.16

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Comparison to Wired Accelerometer

The SmartDiagnostics® wireless vibration sensor was compared to a traditional industrial wired piezoelectric accelerometer (PCB 601A02, 500 mV/g) in a bench test shown in the figure below.

In the following plots, note the time series offset between the SmartDiagnostics® sensor and the piezoelectric accelerometer. The SmartDiagnostics® sensor measures down to 0 Hz and thus the DC signal, typically due to gravity alone, can be observed. In such cases, the DC signal can be used to infer the sensor's orientation; in this case it is shown as 1g because it is nearly vertically oriented. Accurate DC measurements with a traditional piezoelectric accelerometer is not possible due the inherent internal resistance of the piezoelectric transducer.

Despite the difference in the mounting locations of the two sensors, different acquisition timing, and mounting methods, the measurements in the following figure match closely.

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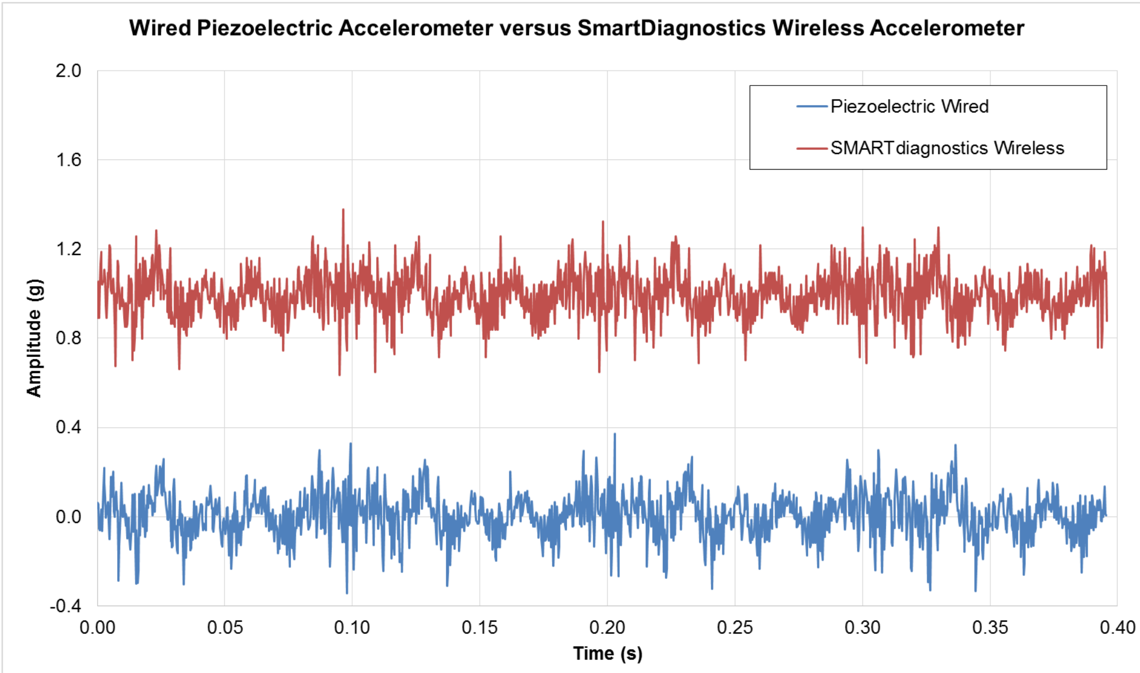

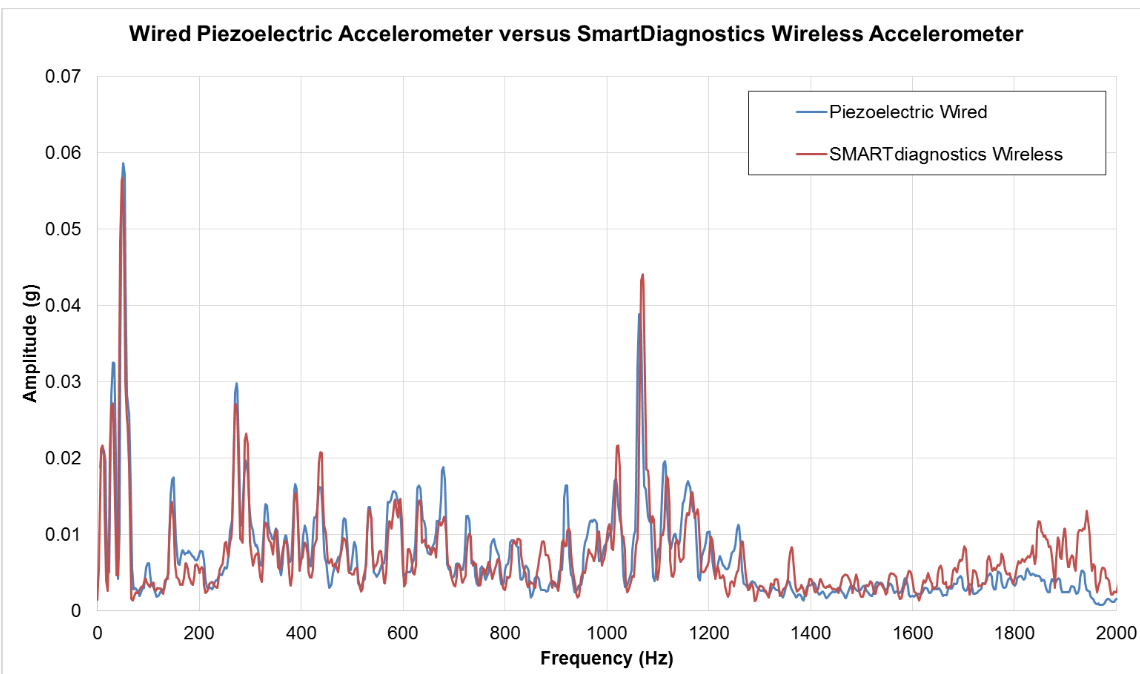

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