PIEZOELECTRIC VS MEMS: FUTURE OF THE VIBRATION SENSORS.

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The paper presents a detail comparison between the traditional piezoelectric and MEMs based vibration sensors. The future prognoses of what technology and where will be used in the future is discussed.

1. Main MEMs parameters important for vibration measurements and diagnostics

There is exit a group of parameters which could be used to define will particular accelerometer is perspective to use for vibration measurements and diagnostics. That group consists of the follow parameters: 1) cost (parts and assembly), 2) required supply power, 3) working frequency range, 4) working temperature range and 5) output noise level. The comparison of the piezoelectric and MEMs based accelerometers by the parameters 1) to 4) is obvious. For instance it is known that for the vibration machinery protection the frequency range of 10-1000 Hz is commonly used, but for diagnostics goals the up frequency is required to be 10-20 kHz. In the same time the parameter 5) – output noise level – is not always clear known for particular application.
Diagram Noise vs Max Working Frequency presented in Figure 1.

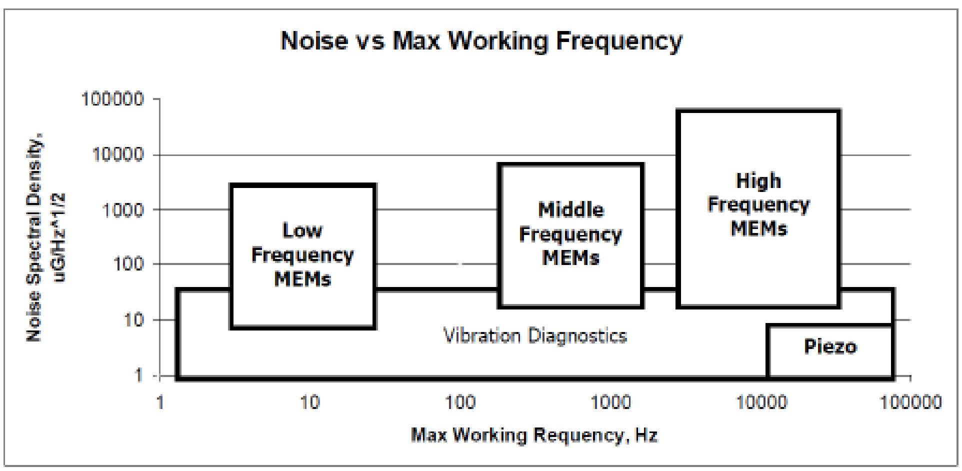
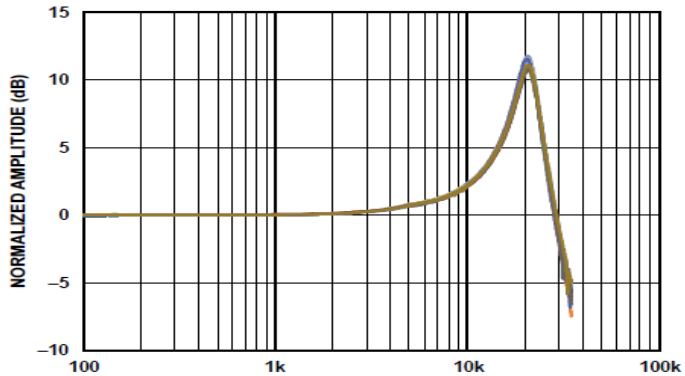
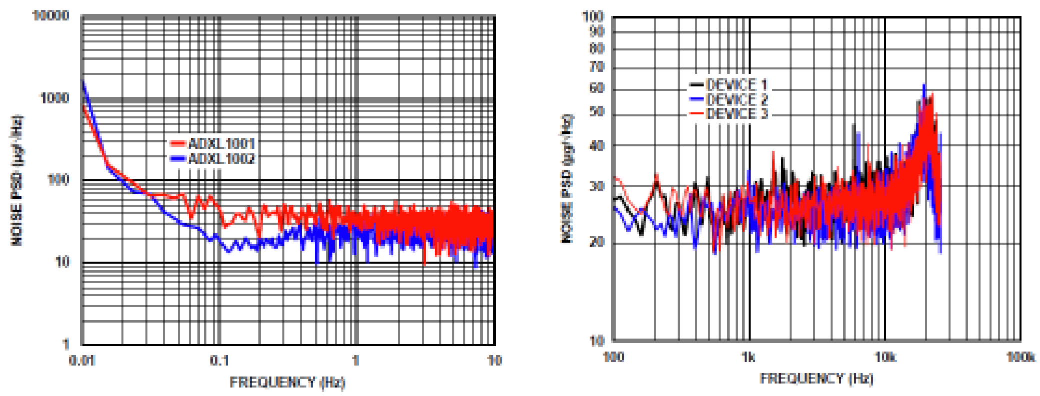


Figure 1. Diagram Noise vs Max Working Frequency

There are some rectangles crosses area usually used for vibration measurement and diagnostics. It is possible to see that some MEMs with noise going down and frequency range being wider could be used in the vibration field. The typical noise and frequency response plots from modern MEMs accelerometer is shown at Figure 2.



a)



b)

Figure 2. Example of modern MEM accelerometer frequency response a) and noise density b) vs frequency

Bellow will be discussed the noise level of the MEMs based Accelerometers and Velocity transmitters.

2. Noise of MEMs accelerometers.

The principle of MEMs accelerometer is illustrated by Figure 3. The external vibration is activates a movement of inertial mass. The integrated electronics provides the output in analog or digital form proportional to that movement by measuring the capacitance between movements and fixes sensor parts. That construction might be considered as mechanical resonator. Then the equation described it movement could be written as follow:

$$\mathrm{M}\frac{\partial^2 x}{\partial t^2} + \gamma \frac{\partial x}{\partial t} Kx = F$$

where M – value of inertial mass, x – displacement of inertial mass, K – coefficient of spring elasticity, γ - spring damper coefficient, F – external forces applied to the inertial mass and t – time.

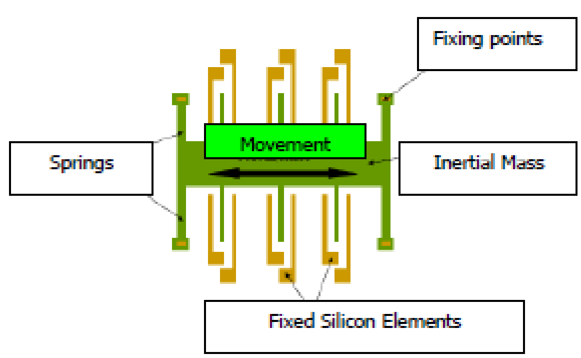


Figure 3. Diagram of the of MEMs accelerometer working principle

This equation could be transformer to the follow $pMv + \gamma v + K / p = F$, where $v = \frac{\partial x}{\partial t} = px$ and p – Laplace operator.
Thus, the square of velocity of noise generation could be equal to:

$$v_{RMS}^2 = \frac{F_{RMS}^2}{\gamma^2 + (\omega M - K/\omega)^2}$$

where ω - circular frequency of inertial Q- mass movement. Using resonance frequency $\omega_0 = \sqrt{K/M}$ and Q-factor $Q = \omega_0 M / \gamma$ the above equition could presented as

$$v_{RMS}^2 = \frac{1}{\gamma^2} \frac{F_{RMS}^2}{1 + Q^2(\omega/\omega_0 - \omega_0/\omega)^2} .$$

The the kinetic energy accumulated in resonator could presented as

$$E = \frac{1}{2} M v_{RMS}^2 = \frac{1}{4\pi\gamma} \int_0^\infty \frac{F_{RMS}^2 Q d(f/f_0)}{1 + Q^2(f/f_0 - f_0/f)^2}$$

where f= $\omega / 2\pi$ и f$_0$= $\omega_0 / 2\pi$. From above equation it is possible to get that $E = F_{RMS}^2 / 8\gamma$ and $F_{RMS}^2 = 4kT\gamma$, where k – is Boltzmann constant and T – is absolute temperature. Then the minimum noise level of the accelerometer is $\sqrt{4kT\omega_0 / MQ}$. At the reasonable values of the Q it should be possible to get minimum spectral noise density for the MEM accelerometer about 1 $\mu G/\sqrt{Hz}$ as of today the best results is about 7-10 times higher. Last years progress of reducing the MEMs accelerometers noise allow us proposing of getting the MEMs accelerometers suitable for any vibration measurements in the temperature range up to 125 degree C.

3. Noise of MEM based velocity transmitters

Vibration velocity in a range of 10 to 1000 Hz is commonly used and standard parameter for machinery protection. There are norms for different types of machinery used in the industries for emergency machinery shutdown when vibration velocity up over the recommended levels. It is typical request that the minimum velocity have to be measured lay bellow 0.01 IPS PK (about 0.1 mm/s RMS). Then it will be nassery to define what the noise level of MEM based accelerometer allows to provide such measurements. Let us do that analyzes with assumption that spectral noise density is constant in a range of 10 to 1000 Hz, which practically truth for almost all MEMs accelerometers (see Figure 2 a). So, accelerometer acceleration noise density A(ω)=ND [$\mu G/\sqrt{Hz}$]. The integrator uses to get the velocity from the acceleration with the transfer function:,
$K(\omega) = K_{INT} / \sqrt{\omega_{INT}^2 + \omega^2}$, where K_{INT} - is integrator gain and ω_{INT} - is integrator low cutoff frequency. Then the velocity spectral density will be:

$V(\omega) = \mathrm{ND\ K_{INT}} / \sqrt{\omega_{INT}^2 + \omega^2}$ and noise velocity RMS in the output of velocity transmitter will be:

$$V_{RMS} = NDK_{INT}\sqrt{\int_{\omega_L}^{\omega_H} d\omega / (\omega_{INT}^2 + \omega^2)} \approx NDK_{INT}\sqrt{\frac{1}{\omega_{INT}} arctg \frac{\omega_H}{\omega_{INT}}}$$

where ω_L - is low frequency of the vibration measurement range and ω_H - is high frequency of the vibration measurement range.
Based on the above equation plots of the velocity noise vs integrator cutoff frequency at different levels of acceleration noise density are presented at Figure 4.
Figure 4 shows that noise density bellow 20 $\mu G / \sqrt{Hz}$ is suitable for most application required vibration velocity measurements.

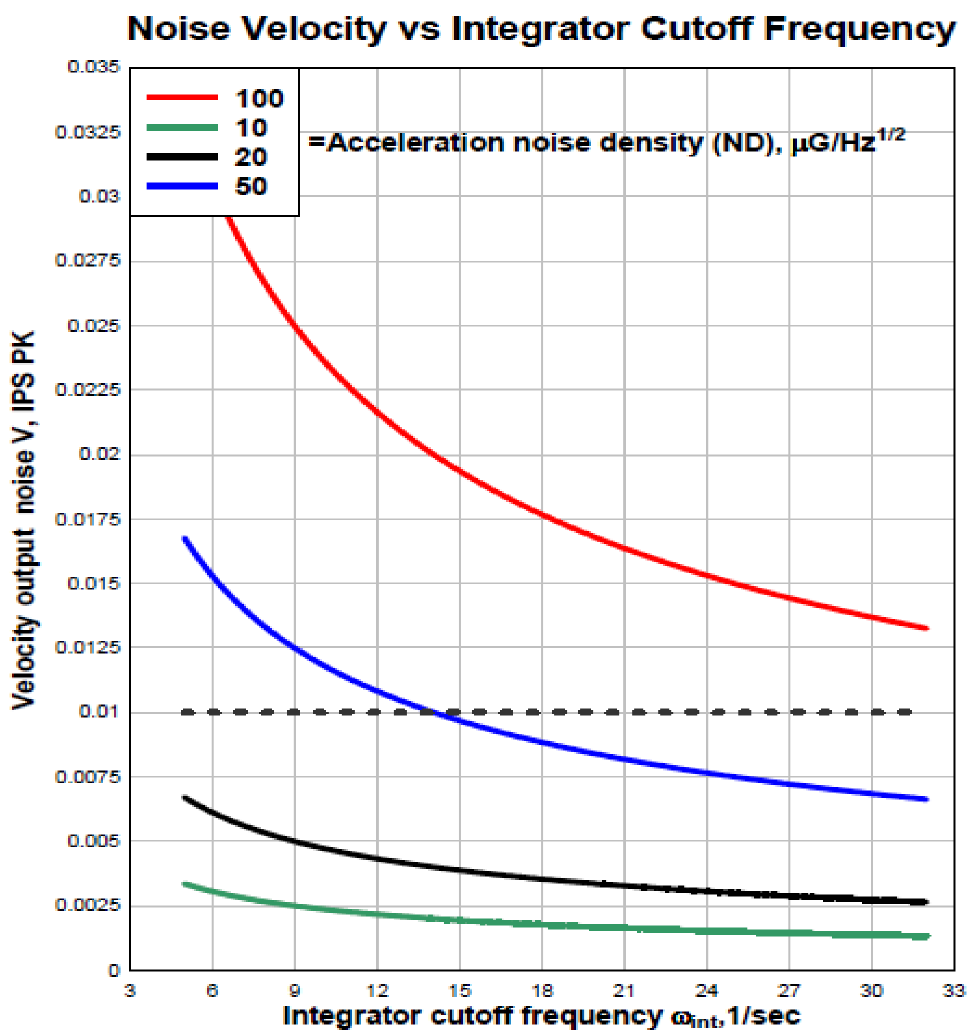


Figure 4. Velocity noise vs integrator cutoff frequency

4. Conclusion

MEMs accelerometers and velocity transmitters have a good chance to take a quite large percent of the niche for vibration machinery measurements and protection in the temperature range up till 125 degree C. Piezoelectric based accelerometers and transmitters will remain for the high temperature applications and the measurements with vary low noise or/and power requirements.