

MCE371: Vibrations

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Handout 11
Fall 2011



Overview of Vibration Measurements

Follow Palm, Sect. pp 425-430 and 559-562.

Additional references:

- Holman, J.P., *Experimental Methods for Engineers*, Mc.Graw-Hill, 8th Edition
- Harris, C.M. and Crede, Ch. (editors), *Shock and Vibration Handbook*, Mc. Graw-Hill, 2nd Edition.

This chapter of the course is just an overview of techniques and equipment for vibration measurements. More detailed studies of vibration measurement are carried out in MCE380: Measurements and Instrumentation Lab and some graduate courses in advanced vibration (MCE512) and mechatronics (MCE603)

Vibration Nomographs

For sinusoidal vibration of the form

$$x(t) = A \sin(\omega t + \phi)$$

we know that the displacement, velocity and acceleration amplitudes are:

$$|x| = A$$

$$|\dot{x}| = A\omega$$

$$|\ddot{x}| = A\omega^2 = \omega |\dot{x}|$$

Taking logarithms:

$$\log |\dot{x}| = \log |x| + \log \omega$$

$$\log |\ddot{x}| = \log |\dot{x}| + \log \omega$$

From the last equation

$$\log |\dot{x}| = \log |\ddot{x}| - \log \omega$$

Vibration Nomographs...

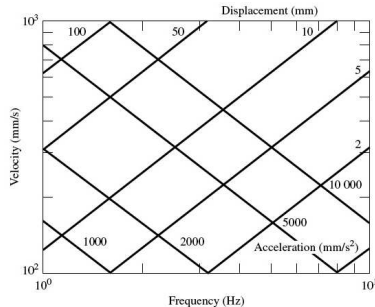
In terms of amplitudes (peaks)

- The log velocity is a linear function of the log frequency, with slope +1 and intercept $\log |x|$
- The log velocity is also a linear function of the log frequency, with slope -1 and intercept $\log |\ddot{x}|$.

Given $A = \log |x|$, we can plot log velocity against log frequency. Varying A gives a family of parallel lines with slope +1. Also, given an acceleration amplitude, we can plot log velocity against log frequency. Varying the acceleration amplitude gives a family of parallel lines with slope -1.

Example

We write Matlab code to reproduce Fig. 7.1-1 in Palm. We use $A = 1, 2, 5, 10, 50$ and 100 mm. For the acceleration we use $1000, 2000, 5000$ and 10000 mm/s². The frequency axis ranges between 1 and 10 Hz, while the velocity axis ranges between 100 and 1000 mm/s.



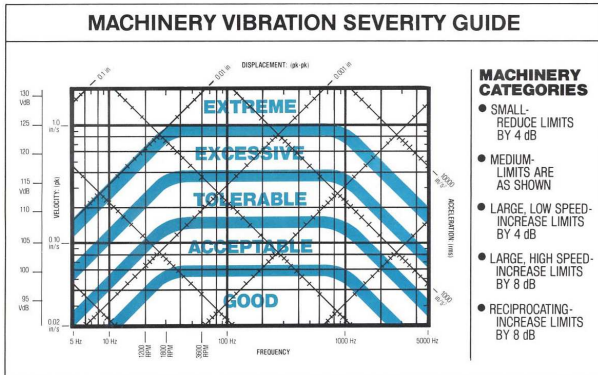
Admissible Vibration Levels in a Nomograph

The maximum vibration that can be tolerated by humans or machines are given by a combination of displacement, velocity and acceleration limits.

These limits may vary with frequency.

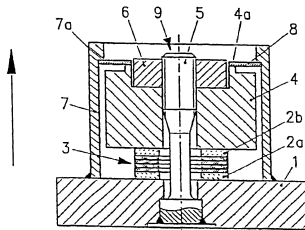
- 1 It is not the same to sustain a 1mm displacement amplitude at 1 Hz than at 1000 Hz. Should the tolerable displacement increase or decrease with frequency?
- 2 Displacement amplitude limits as a function of frequency can be plotted in a typical Bode plot.
- 3 Maximum absolute accelerations also apply across all frequencies (remember that acceleration is proportional to force)
- 4 Maximum absolute velocities may also apply.
- 5 A nomograph can be used conveniently for the 2 last kinds of limits (see Palm, Fig. 7.1-2)

Example: Structural Vibration Limits

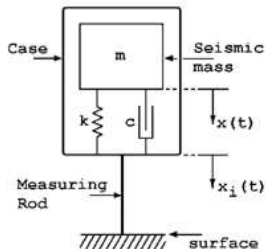


As part of this course, we find the boundaries for acceptable vertical vibration for a small CD player (for skip-free operation).

The Seismic Accelerometer



Seismic Accelerometer Analysis



It's just a mass-spring-damper system with base excitation. Recall the force transmissibility formula (Eq. 4.3-13 in Palm)

$$F_t = kYr^2 \sqrt{\frac{4\zeta^2 r^2 + 1}{(1 - r^2)^2 + 4\zeta^2 r^2}}$$

Seismic Accelerometer Analysis...

Note that $Yr^2 = (Yw^2)/w_n^2$, where (Yw^2) is the harmonic acceleration amplitude, call it a . Then

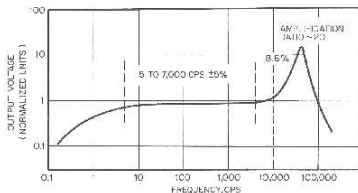
$$F_t = a(k/w_n^2) \sqrt{\frac{4\zeta^2 r^2 + 1}{(1 - r^2)^2 + 4\zeta^2 r^2}}$$

The term in the square root is practically constant when $r \ll 1$ and ζ is not too small. That is, the force sensed by the piezoelectric disk is practically proportional to acceleration for well-damped systems away from $r = 1$.

Seismic Accelerometer Analysis

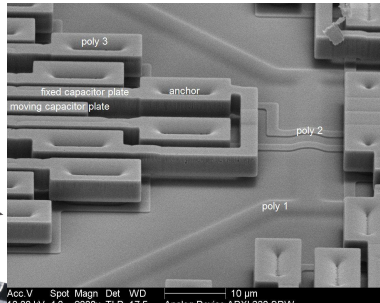
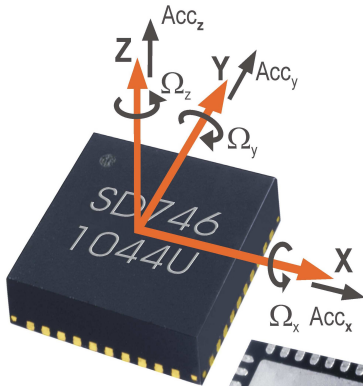
Unfortunately, the conversion from sensed force to output voltage is not that simple. The piezoelectric ceramic produces electric charge in proportion to force, but a direct charge readout is not reliable due to uncertainty in the capacitance of the cables. (remember $V = q/C$).

A *charge amplifier* is an electronic device providing an output voltage proportional to charge when operated above certain threshold frequency. Constant accelerations cannot be measured. The overall instrumented accelerometer response looks like this:



MEMS Accelerometer

MEMS stands for micro-electro-mechanical systems technology. A MEMS device contains small-scale components (1 to 100 micrometers) acting as inertial masses and stiffnesses. Their motion is sensed by electromagnetic or electrostatic means. The whole package, called *lab on a chip* can be embedded in electronic packaging as a self-contained unit.



Electrodynamic Shaker

A shaker is a 1D vibration exciter driven by voltage. They are available from small table-top units to 20-ton devices that need water cooling.



In-class demo: Accelerometer Calibration

We use a MEMS accelerometer with a sensitivity of 1 V/g to calibrate a seismic accelerometer. Equipment:

- 1 ± 1.7 g MEMS accelerometer on evaluation board with analog output. ADXL203.
- 2 Electrodynamic shaker (vibration exciter)
- 3 Amplified function generator to drive shaker
- 4 4-channel oscilloscope
- 5 PCB 303A SN 2405 piezoelectric accelerometer
- 6 PCB ICP charge amplifier

Vary the excitation frequency between 25 and 95 Hz, at 10 Hz increments. Record the MEMS and piezo accelerometer output voltage amplitudes for each frequency.