Precision Machine Design-Acoustic Isolation

Ultra-precision machines are also influenced by the acoustic wave or sound pressure wave, when they are exposed to acoustic noise environment.

In this case, the best solution is to move away machines from the noisy environment, in order to escape from the noise headache.

Otherwise, proper acoustic enclosures are to be designed to give isolation from acoustic disturbance, which is called as acoustic isolation.

This chapter is to deliver the knowledge and methods for acoustic isolation or noise control in view of the precision machine design.

Acoustic wave or sound wave:

Sound is a propagation of air pressure through media.

Once sound is generated, then propagated through media in the form of lateral wave of pressure in the direction of travelling.

Followings are some terminology for sound or acoustic wave.

Let C be the speed of sound, or speed of acoustic wave;

$C=f\lambda$

where λ=wavelength of sound wave,

f=frequency of wave [Hz]

One octave band with central frequency f_c indicates

$f_c 2^{-1/2} \le f \le f_c 2^{1/2}$

One third octave band with central frequency f_c indicates

$f_c 2^{-1/6} \le f \le f_c 2^{1/6}$

$C=[E/\rho]^{1/2}$ for solid media,

where E=Young's modulus, ρ is the density

$C=[\gamma P/\rho]^{1/2}$ for gas media

where γ=ratio of specific heat=Cp/Cv, P=Pressure, ρ=Density

$C = 331.5 + 0.6T$ for air [m/s]

where T is temperature of air [˚C]

Hearable pressure range: 2×10^{-5}Pa ~ 60Pa, where $1Pa = 1N/m^2$

Hearable freq. range: 20Hz~20,000Hz

SPL (Sound Pressure Level) $= 20 \text{Log}_{10} Pe/Po$ [dB]

where Po is 2×10^{-5} Pa, Pe is the effective pressure

PWL(Power Level)$= 10 \text{Log}_{10} W/W_0$ [dB]

where W=power of sound in [W], $W_0 = 1\times10^{-12}$ W

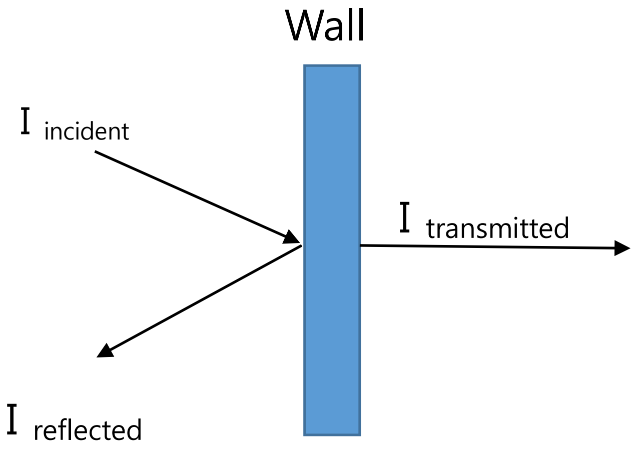
IL(Sound Intensity Level)$= 10 \text{Log } I/I_0$ [dB]

where I =Intensity of sound [W/m^2]

$I_0 = 1\times10^{-12}$ W/m^2

Transmission of Sounds through Structures

This section is mainly sourced from Lamancusa's PDF file on Noise Control (source: https://www.mne.psu.edu/lamancusa/me458/9_trans.pdf)



Transmission Coefficient, τ

$\tau = I_{transmitted} / I_{incident}$

where τ is a frequency dependent physical property of material.

When the wall or partition consist of several materials, then the composite transmission loss, $\tau_{composite}$, is calculated as

$\tau_{composite} = \Sigma\tau_i S_i / \Sigma S_i$ for i=1,2..n

where τ_i= Transmission Loss of each material

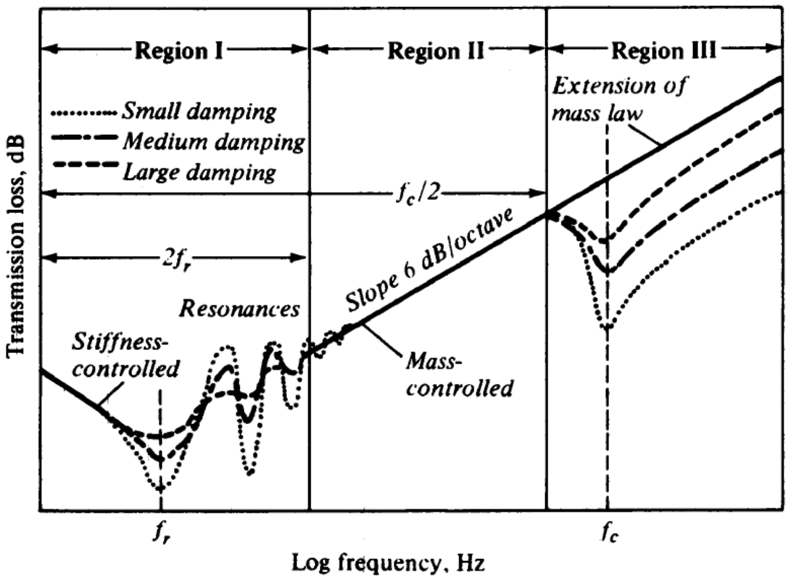
S_i= Area of each material

STL(Sound Transmission Loss)

= Log ratio of the incident to the transmitted energy

=10 $\text{Log}_{10}\ 1/\tau$ in [dB]

The STL is highly depending on the frequency, and theoretical STL is typically shown in fig.



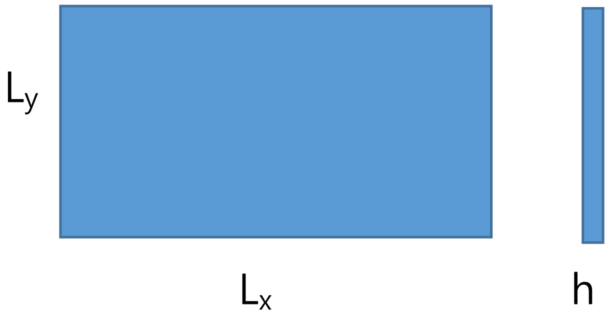
Theoretical Transmission Loss for an infinite homogeneous panel

(source: https://www.mne.psu.edu/lamancusa/me458/9_trans.pdf)

Region1: This region, stiffness controlled region, is mainly influenced by the bending stiffness, resonance, and damping of the panel, and this region spans the frequency range upto twice of resonant frequency, f_r, of the panel.

For the resonant freq, f_r, of panel can be analytically obtained as the lowest natural frequency;

Natural freq. of a rectangular plate of L_x X L_y X h,



The natural frequency, F , of simple supported plate is;

$F(N_x, N_y)=[\pi/2][Eh^2/(12\rho)]^{1/2}[(N_x/L_x)^2+(N_y/L_y)^2]$

where E=Young's modulus; ρ=density;

N_x=number of half sine waves along x axis

N_y=number of half sine wave along y axis

The Mode shapes of the plate is;

$Z(x,y)=A \sin N_x \pi x/L_x \sin N_y \pi y/L_y$

Region2: This region, mass controlled region, is mainly influenced by the mass of the panel, and follows fairy well the curve of slope 6dB/octave. The STL is theoretically given by

$$STL=10 \text{ Log } \{1+[\omega\rho_s/2\rho c]^2\} \text{ [dB]} \qquad \text{eq}$$

where ω=sound frequency [rad/sec]

ρc=Impedance of medium (density X velocity)

=415 rayls for air at standard temperature and pressure, and 1 rayl =1 Pa/m/s

ρ_s=mass of panel for unit surface area

This equation indicates STL increase 6dB when either sound frequency(ω) or panel mass per unit area(ρ_s) is doubled,

or Slope=6dB/octave in Log graph

[$\because$ when $\omega \rightarrow 2\omega$;

$STL' = 10 Log[2\omega\rho_s/2\rho c]^2 = 10\{Log 4 + Log[\omega\rho_s/2\rho c]\}$

$= 10 Log 4 + 10 Log[\omega\rho_s/2\rho c] = 6 + STL$

$\therefore$ STL increase by 6 when freq. doubles]

In this region, the frequency ranges from 2fr to fc/2, where fc is the critical frequency that will be explained in region 3.

Region3: This region is influenced by the coincident effects, in which the sound wavelength coincides with the structural wavelength such as bending waves (or flexural waves) that deform the structure transversely as they propagate in longitudinal direction. It is also called as radiation of sound wave.

For a homogeneous infinite plate,

the critical frequency, fc, is

$fc=5.2e10\rho/hE$ [Hz]

where ρ=weight density[lbf/in^3], h=plate thickness [in],

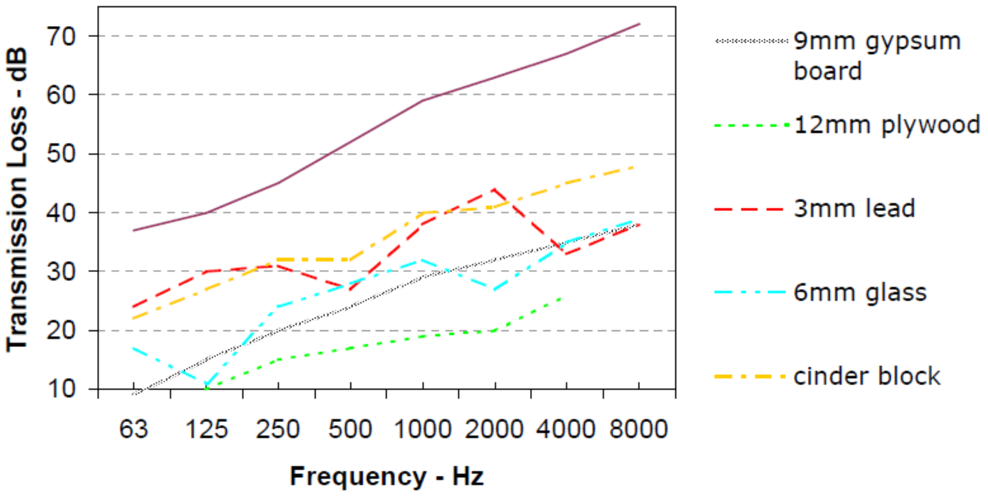
E=Young's modules [psi]

fc=500/h for glass, steel, Al (all have similar ρ/E);

fc=790/h for plywood

In this region, the frequency ranges upward from fc/2.

Fig. shows practical a STL graph for typical materials for barrier.



STL for typical materials

(Source:https://www.mne.psu.edu/lamancusa/me458/9_trans.pdf, Bies and Hansen)

In summary; acoustic isolation enclosure or barries should be designed.

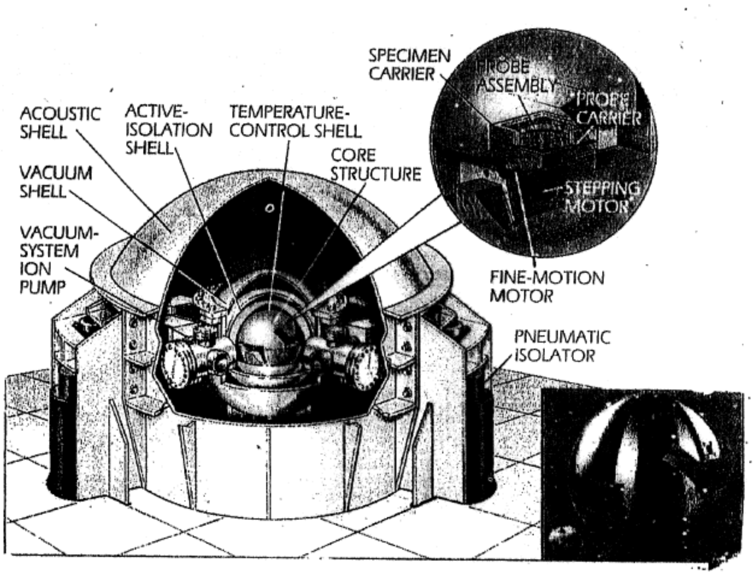
Material properties for barrier material and the acoustic isolation:

-High density material gives high STL in mass controlled region

-Low bending stiffness material for high STL to give lower f_r

-High internal damping material to prevent the resonant modes

Therefore, the ideal barrier material should have high density and low bending stiffness, (i.e. very limp). In the past, lead sheet or leaded vinyl was widely used until it was kicked out due to the environmental issue. Nowadays, loaded vinyl, that is impregnated with non-lead metal can be used. High density with low strength gives very high critical frequency, which is desirable. Gypsum board is a good barrier material and is more effective than plywood. Loaded vinyl or vinyl impregnated with metal fillings, is a common material for high STL.



SCHEMATIC OF M-CUBED

Vibration Isolation and Acoustic Isolation

(source: NIST's M-Cubed)