BME-ISE 564 Occupational Ergonomics and Biomechanics

Occupational Noise and Vibration

Aakash
(https://nimrobotics.com)

Based on content developed by Dr. Robert Radwin, University of Wisconsin-Madison

Interested in healthcare work as an industrial engineer?

Facilitate process improvement work in a hospital setting

Learn lean management

Collaborate with other student interns and healthcare professionals

UWHealth

Organizational Improvement Internship Program

Position Details

- ***Work Hours: ~10 hours /week during school year***
- ***Compensation: $17 /hour***
- ***Location: Remote with on-site opportunities***
- ***Potential full-time hire post-graduation***

Recruitment Timeline

- *Intern – Organizational Improvement* job posted on uwhealth.org/careers beginning of May
- Interviews in June
- Hiring decisions made beginning of July
- Position start dates end of August!

Sign up to receive updates on the job posting date here!

@Claire

Logistics

- Homework
- Exam 2
  - Released 4/22
  - Due 4/29
  - Everything except last week

Week	Date	In-Class Topic [1]	On-Line Assignment [2]
1	January 24	Course Introduction [3] Note: Meets in Room 324 Wendt Commons	Design for Human Variability and Engineering Anthropometry
2	January 31	Design for Human Variability and Engineering Anthropometry [3] Note: Meets in Room 324 Wendt Commons	Anthropometrics Design
3	February 5	Anthropometrics Design	Timed Activity Analysis
4	February 12	Timed Activity Analysis	Muscular Contraction and Strength
5	February 19	Muscular Contraction and Strength	Biomechanics and Design for Strength
6	February 26	Biomechanics and Design for Strength	Circulation and Energy Demands of Work
7	March 4	Circulation and Energy Demands of Work	Work-Rest Cycles and Energy Expenditure Prediction
		Exam 1[4] due before Midnight, March 11	
8	March 11	Work-Rest Cycles and Energy Expenditure Prediction	Occupational Thermal Stress
9	March 18	Occupational Thermal Stress	Biomechanical Models of Lifting
	March 25	**Spring Break**	
10	April 1	Biomechanical Models of Lifting	NIOSH Equation and Design of Manual Materials Handling Tasks
11	April 8	NIOSH Equation and Design of Manual Materials Handling Tasks	Occupational Noise and Human Vibration
12	April 15	Occupational Noise and Human Vibration	Upper Limb Musculoskeletal Disorders
13	April 22	Upper Limb Musculoskeletal Disorders	Surveillance for Musculoskeletal Disorders
		Exam 2[4] due before Midnight, April 29	
14	April 29	Surveillance for Musculoskeletal Disorders	
		Design Project Report due before Midnight, May 7	

Vibrations

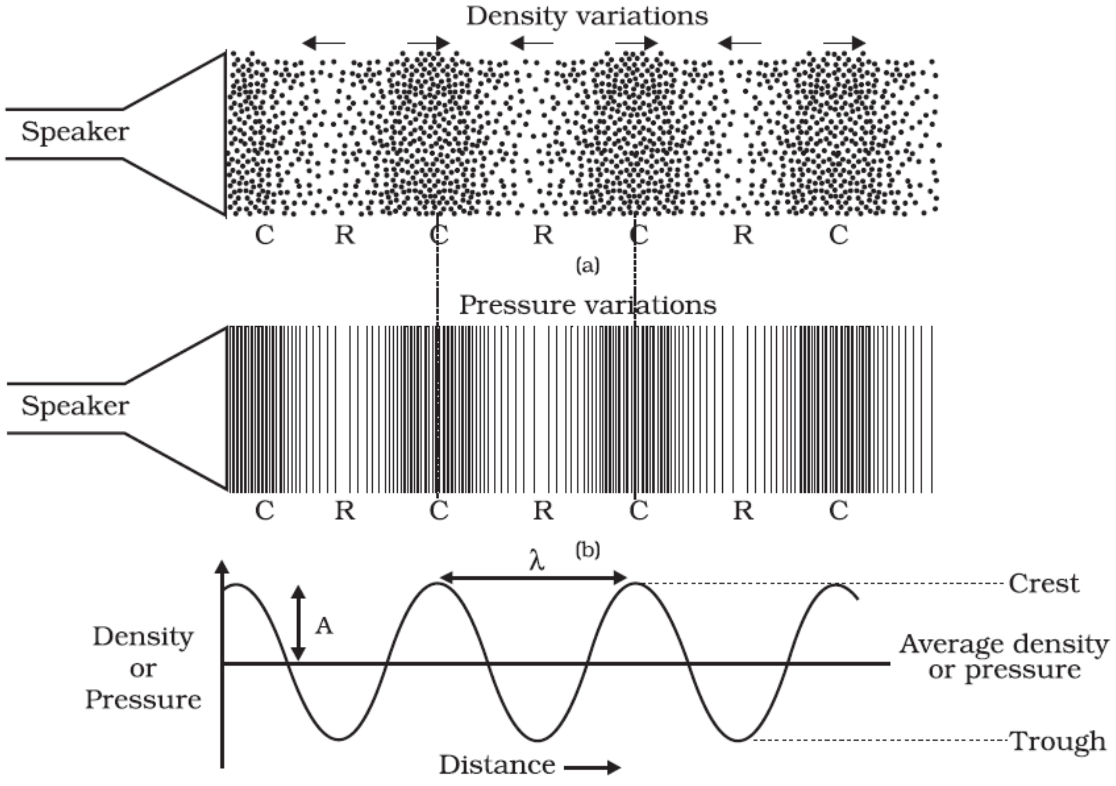
- What?
- Why?
- Sound?
- How to measure and prevent?

Sound

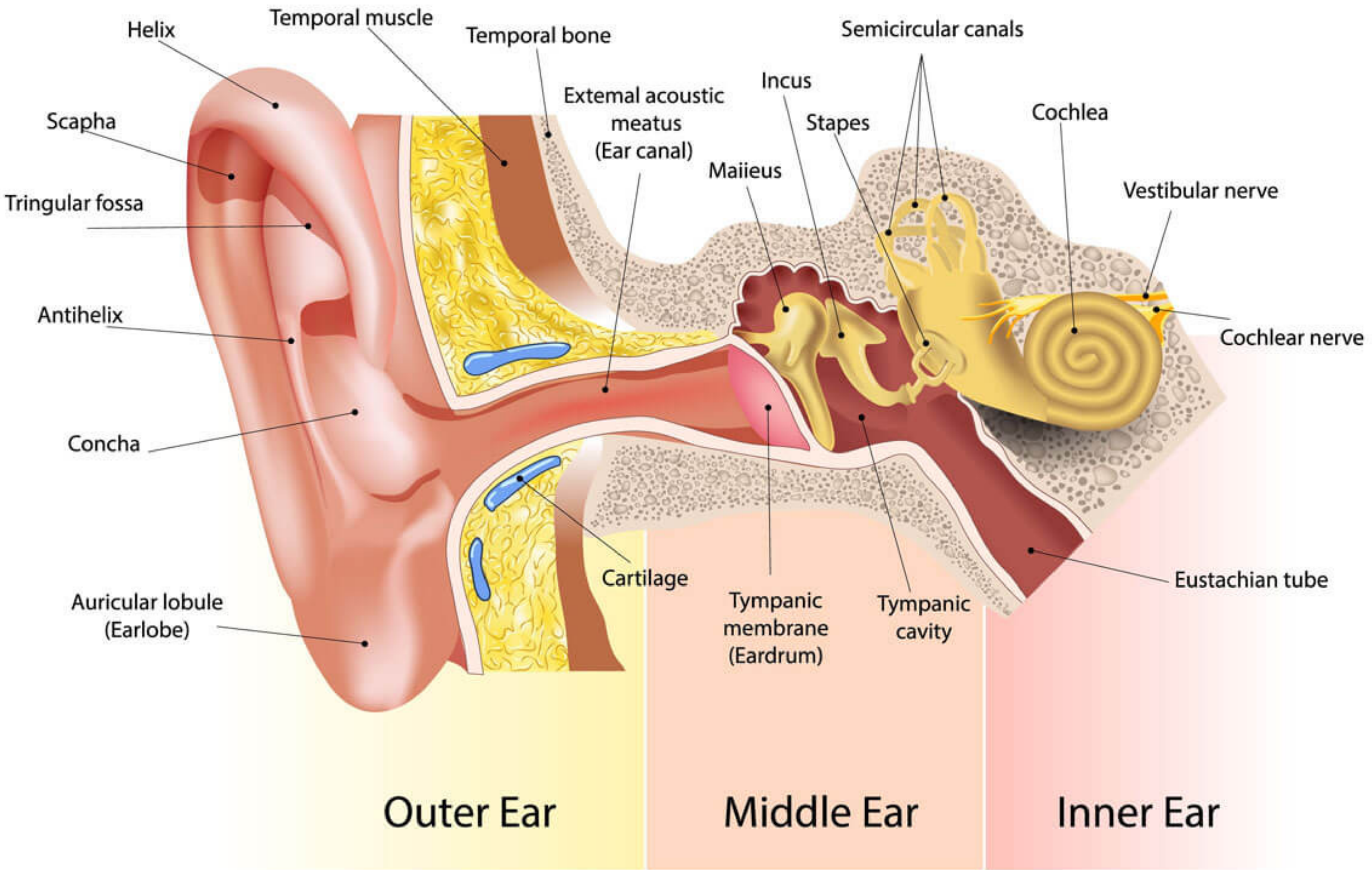
- Sound
  - oscillating pressure wave
  - Requires a medium

$$\lambda = v \times T$$

$$f = \frac{1}{T} = \frac{v}{\lambda}$$



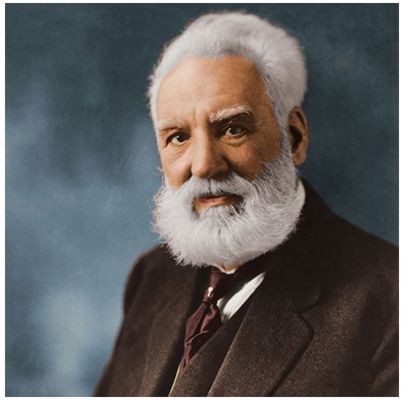
Byjus.com



https://www.happyearshearing.com/anatomy-of-the-ear/

Sound Pressure Level (SPL)

- Sound intensity is measured by sound pressure level
- Ratio of sound pressure and reference pressure
- Decibels (dB)

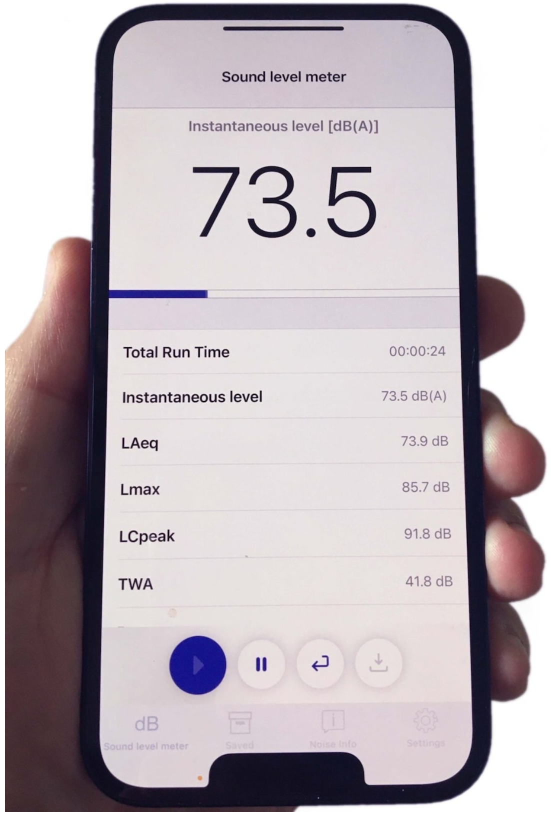


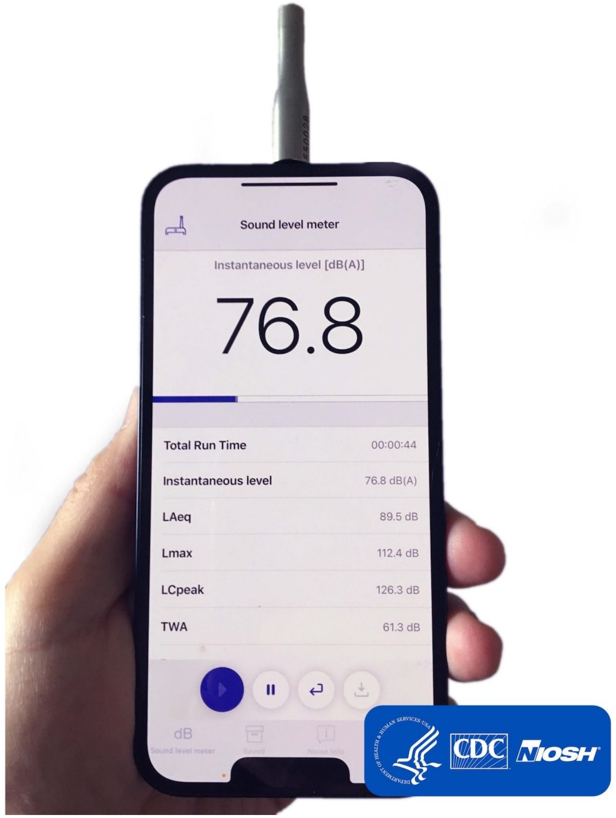
$$SPL = 10 \times \log_{10} \left(\frac{p}{p_o} \right)^2 = 20 \times \log_{10} \left(\frac{p}{p_o} \right)$$

$$p_o = 20 \times 10^{-6} \text{Pa}$$

Source	Power Level (dB)
Whisper	50
Voice (conversational)	70
Voice (shouting)	90
Stereo (loud)	100
Truck horn	110
Airplane engine (propeller)	120
Pipe organ (peak)	130
Jet	140

NIOSH Sound Level Meter App





*iOS only :(

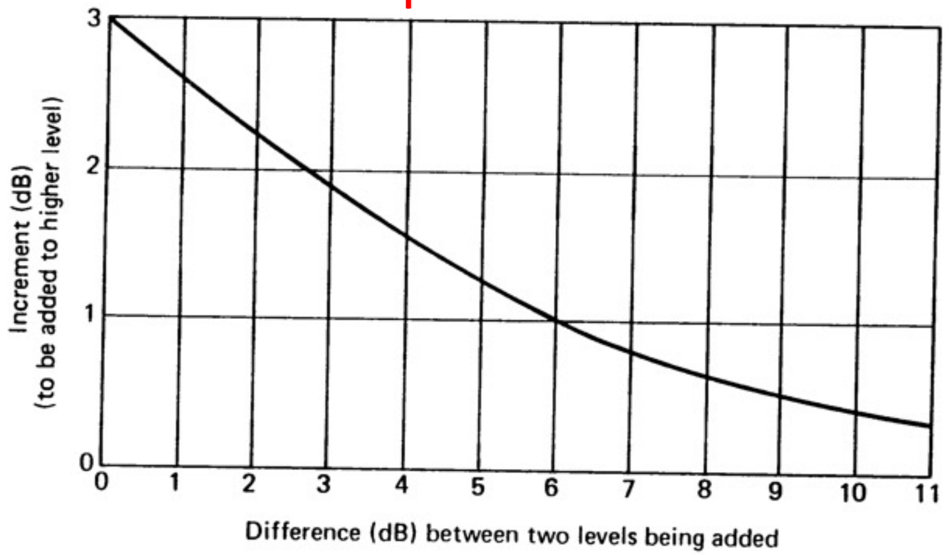
Decibel Addition

Analytical addition

$$L_{\text{total}} = 10 \times \log_{10}\left(\sum_i 10^{\frac{L_i}{10}}\right)$$

$$L_{\text{total}} = 10 \times \log_{10}\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}}\right)$$

Graphical addition

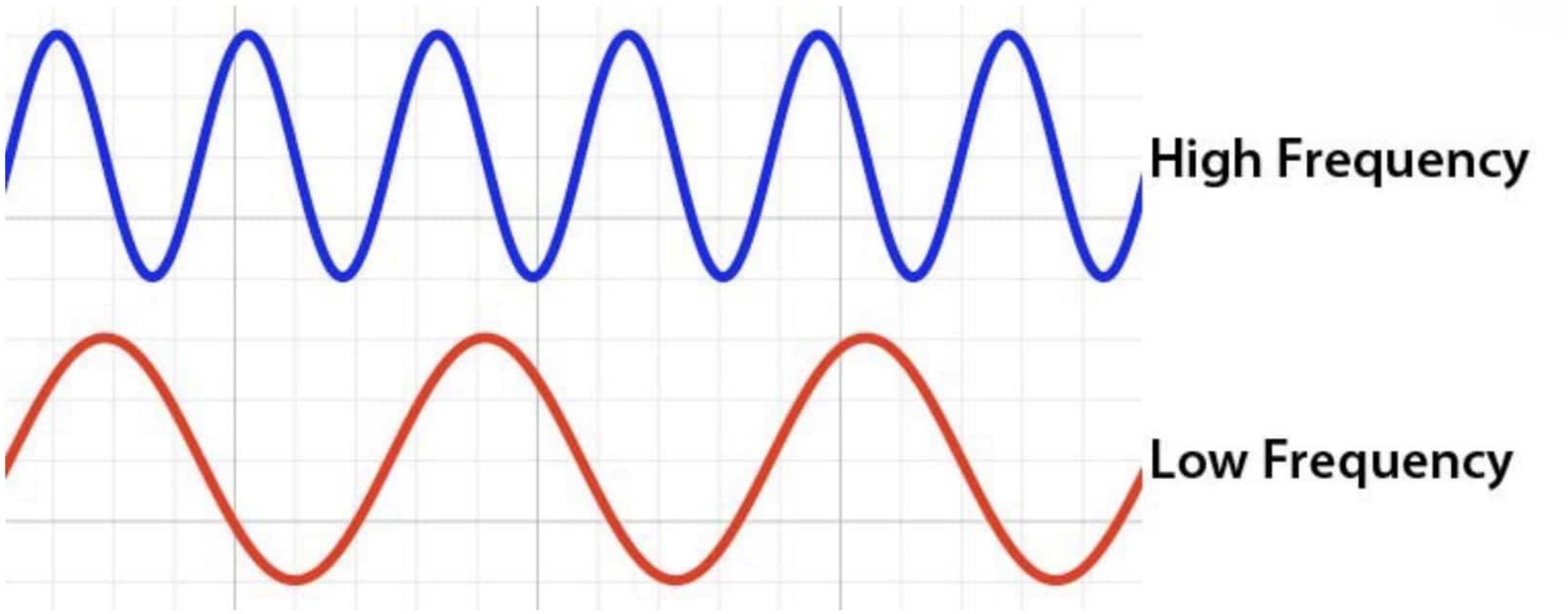


Start with smallest two pairs and progressively add

Difference in Levels (dB)	Add to Higher Noise Level (db)
0 – 1.5	3
1.6 – 3	2
3.1 – 5	1.5
5.1 – 9	1
> 9	0

Sound Frequency

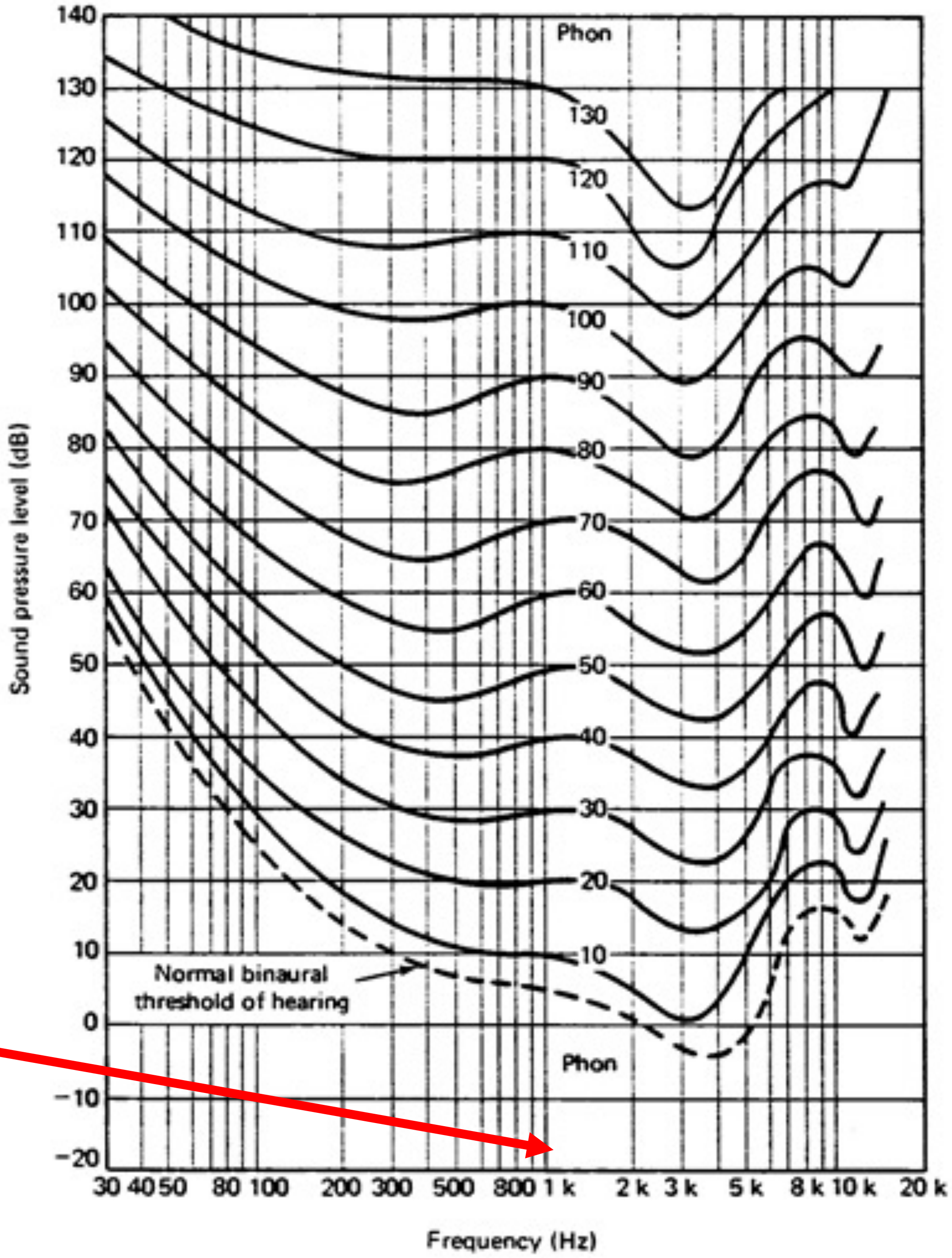
- Unimpaired hearing: 20 Hz to 20,000 Hz
- Play https://onlinetonegenerator.com/



https://unison.audio/frequency-range/

Loudness

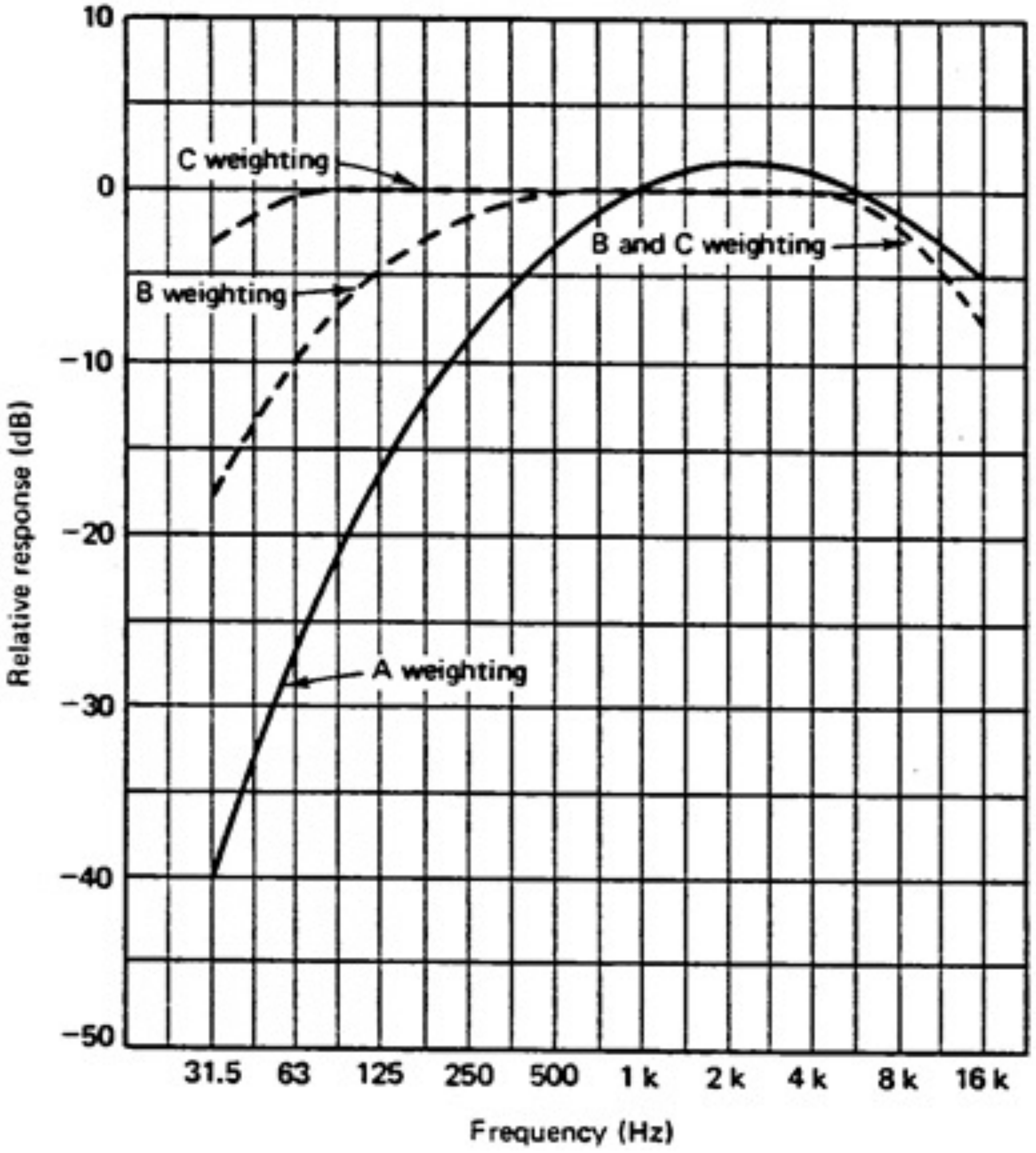
- Nonlinear function of both intensity and frequency



The level phons is the sound pressure level at 1,000 Hz.

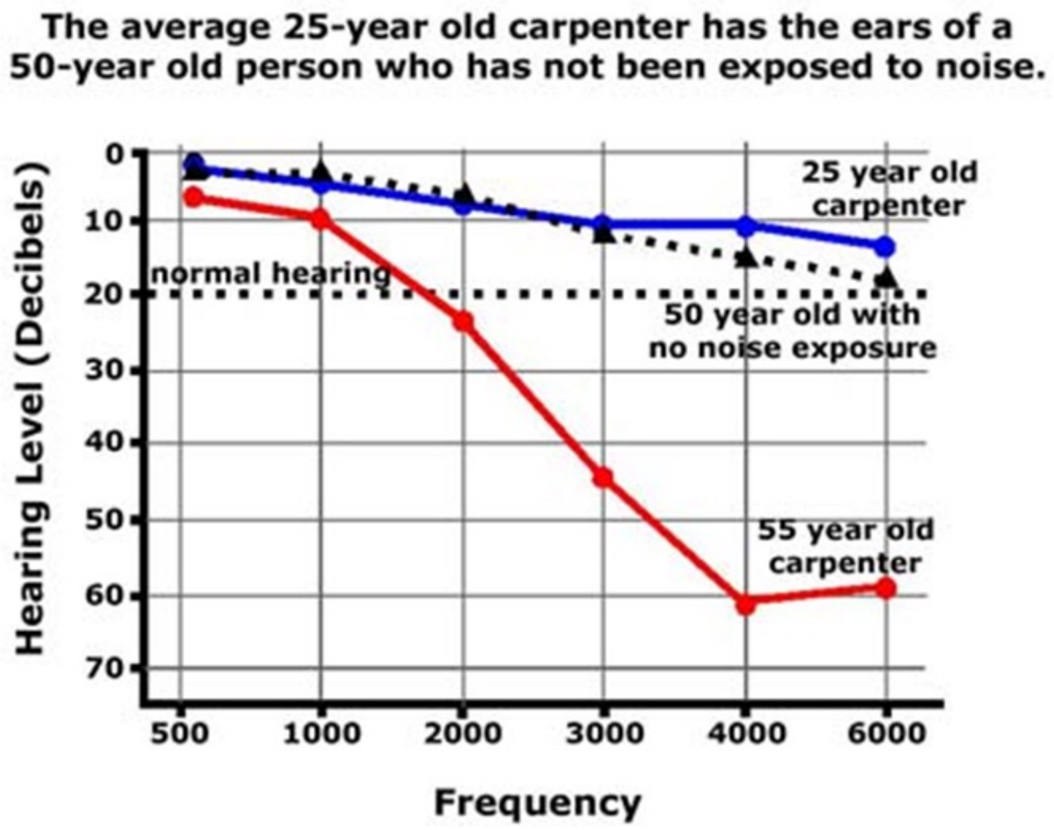
Frequency weighted sound levels

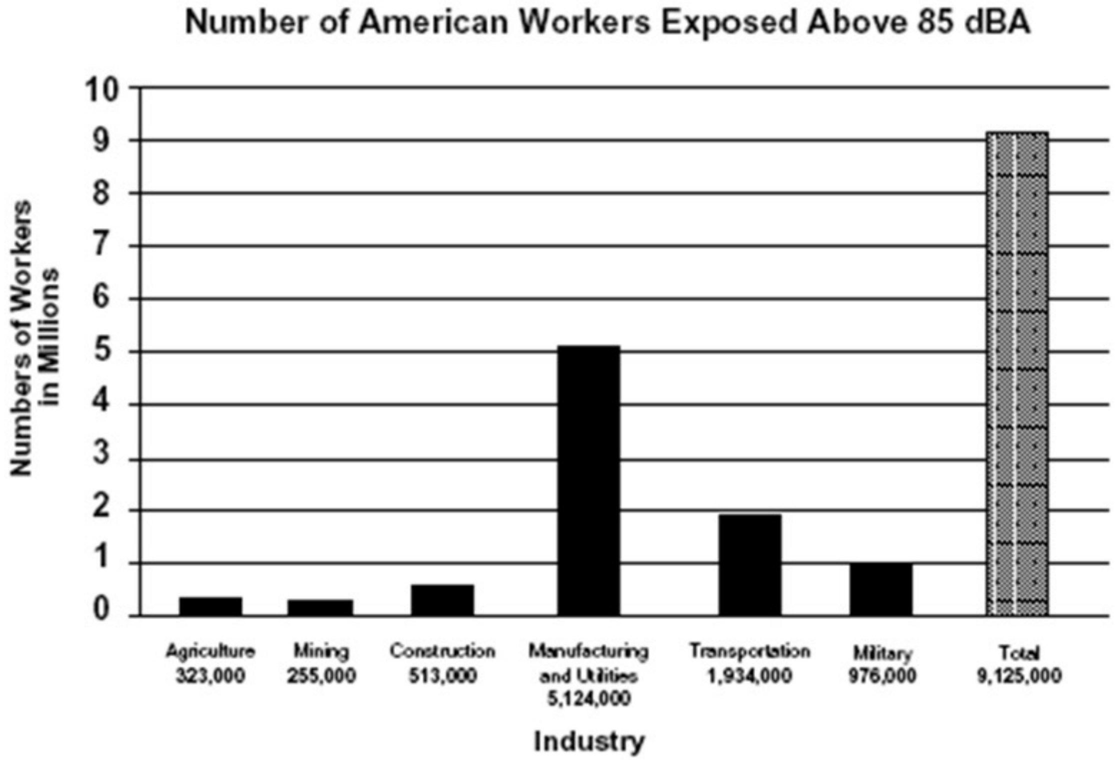
- Standard filter networks are used for measuring sound pressure levels. These networks are called A weighting scales, and they're based on the frequency hearing characteristics of humans. There are also B and C weighting scales, but these are not matched to human hearing frequency characteristics. The common sound level measurement is the A weighted scale and deemphasizes frequencies that are below 1,000 Hz and above 1,000 Hz.



Sound level Meter

Occupational noise hazards quantification





Daily Noise Exposure Limit

Duration per day (hours)	Sound Level (dBA)
16	85
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
.5	110
.25 or less	115

Noise Dosage

- T_i = duration
- L_T = recommended exposure level
- D>1 hazardous

$$D = \sum \left(\frac{T_i}{L_T} \right)$$

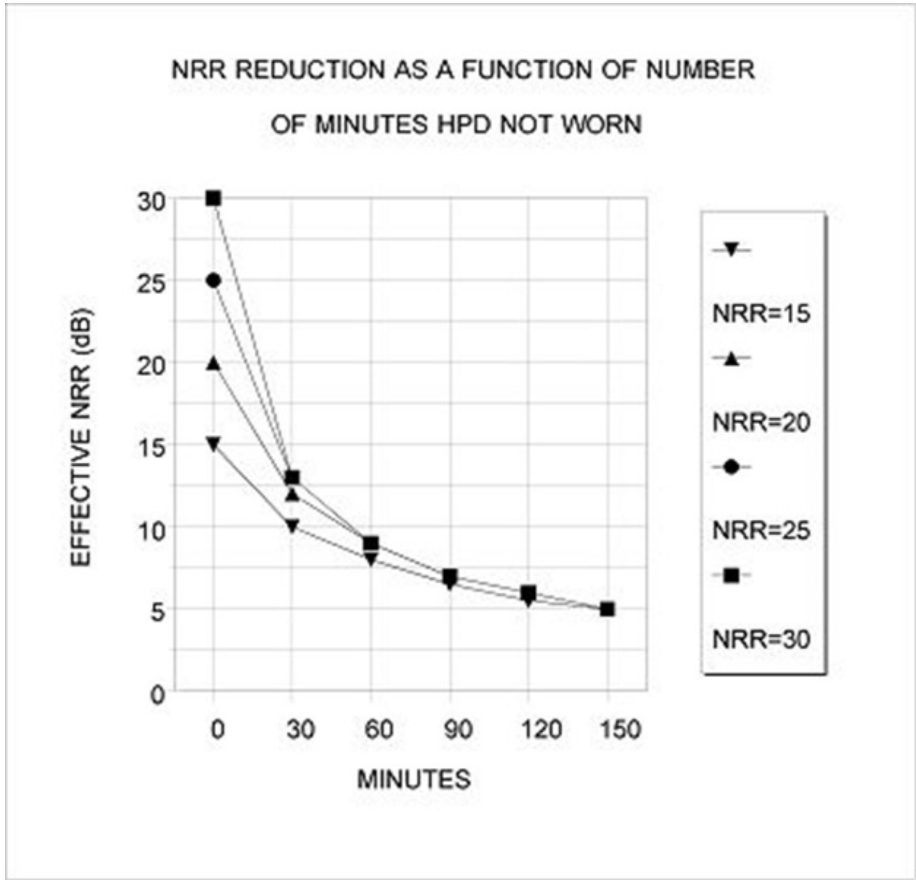
Time Weighted Average (TWA)

$$T(\mathrm{Hr}) = \frac{8}{2^{(L-90)/5}}$$

$$\mathrm{TWA(dB)} = \frac{1}{\sum T_i} \sum L_i T_i$$

$$\mathrm{TWA(dB)} = 16.1 \times logD + 90$$

Countermeasures

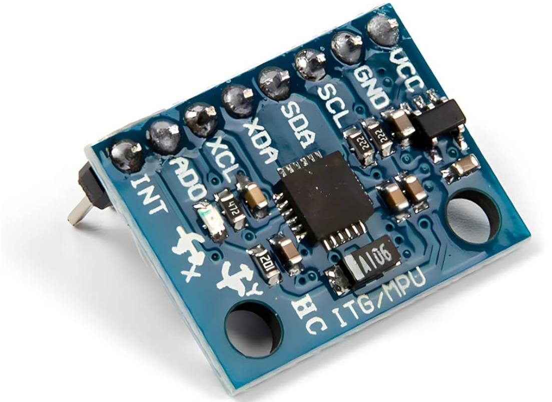


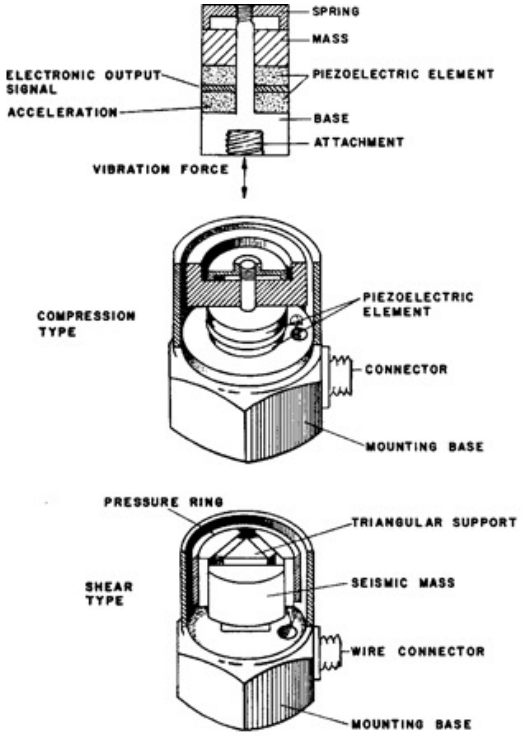
$$\text{Decibel reduction} = \frac{\text{NRR} - 7}{2}$$

Important to keep using the hearing protection

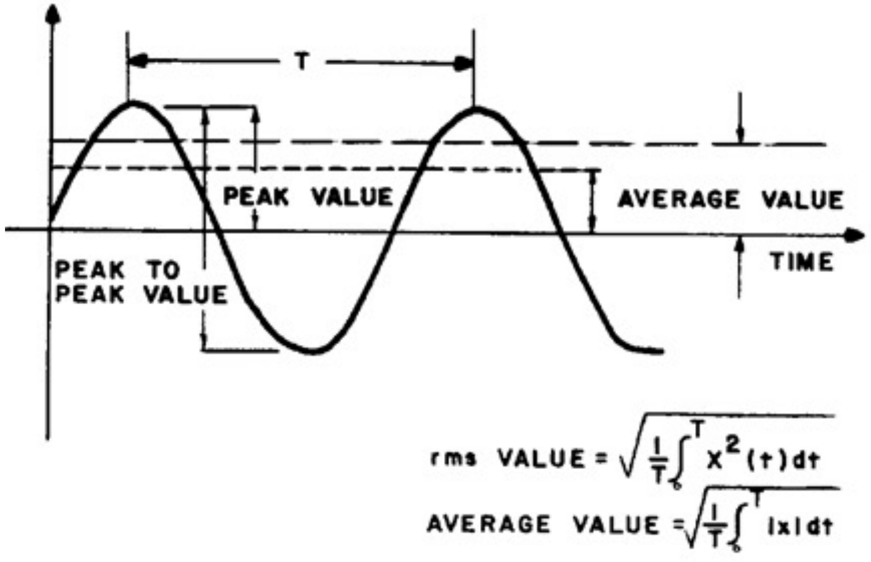
What is human vibration?

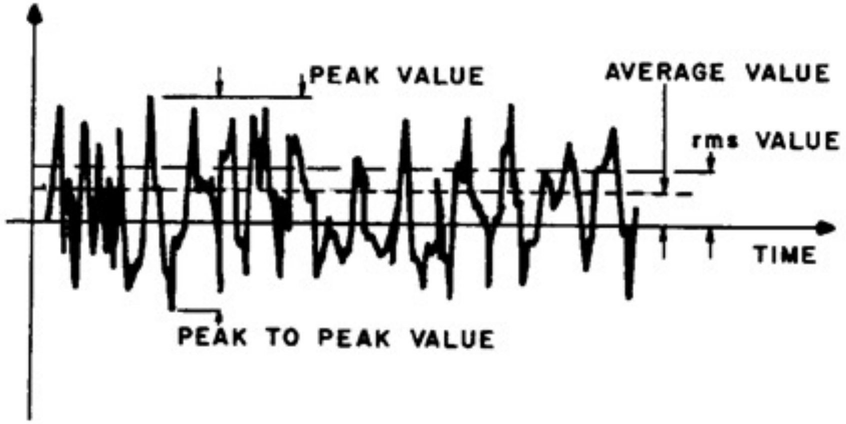
- Humans are exposed to vibration when they ride in vehicles or operate machinery or tools that make rapid movements, like a reciprocating sander.
  - Whole body vibration
  - Hand and arm vibration



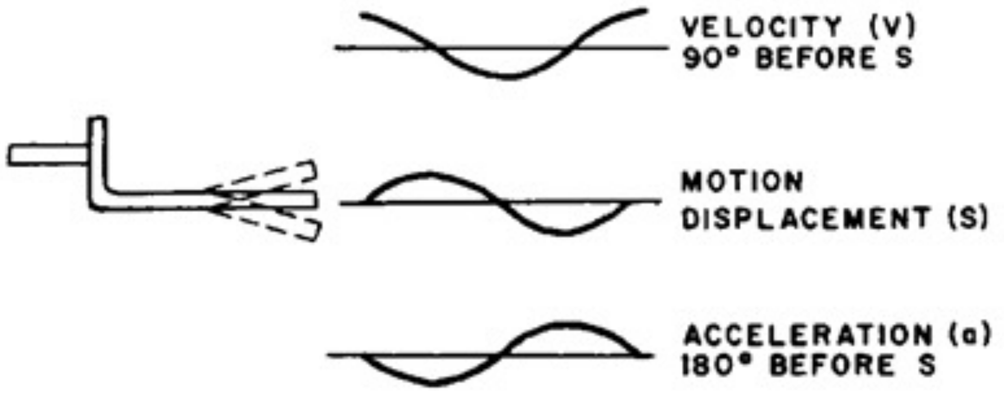


Accelerometers





Displacement, velocity, acc/n



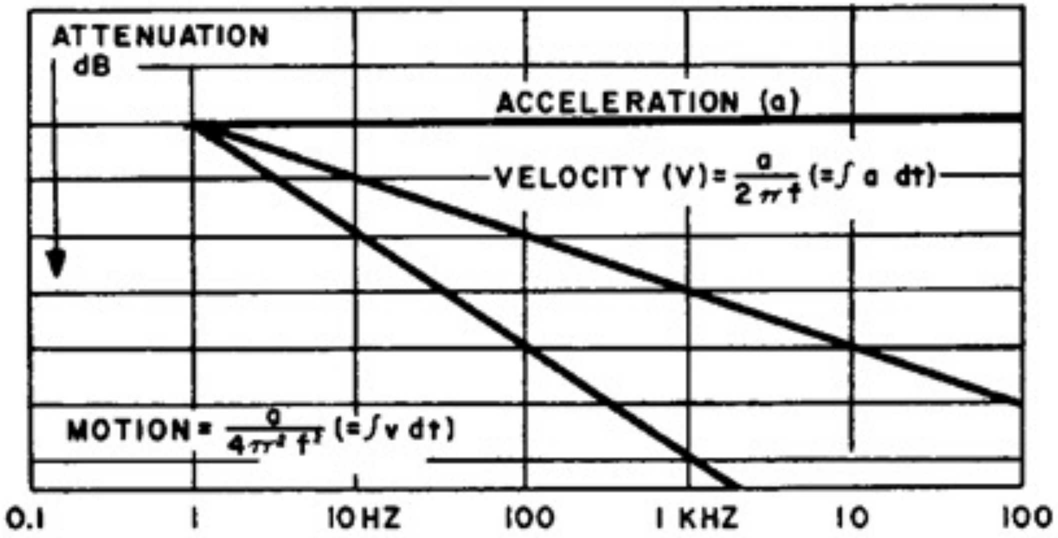
$$v = \int a \, dt$$

$$s = \int v \, dt$$

If the vibration is sinusoidal

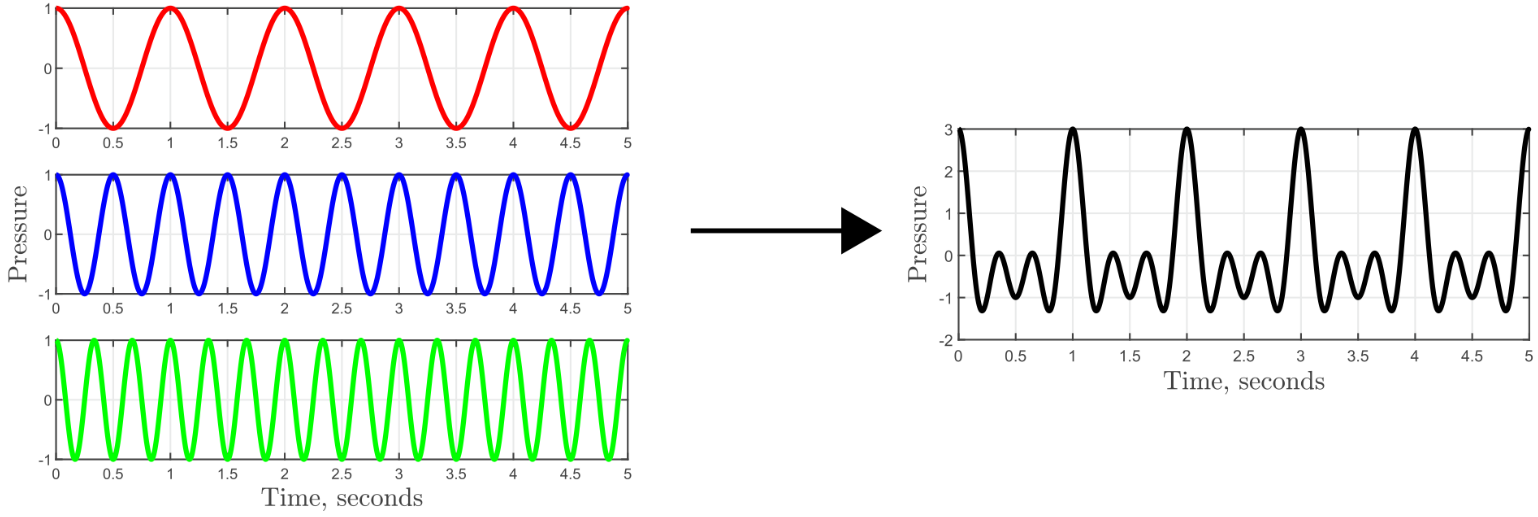
$$v = \frac{a}{2\pi f} = \int a \, dt$$

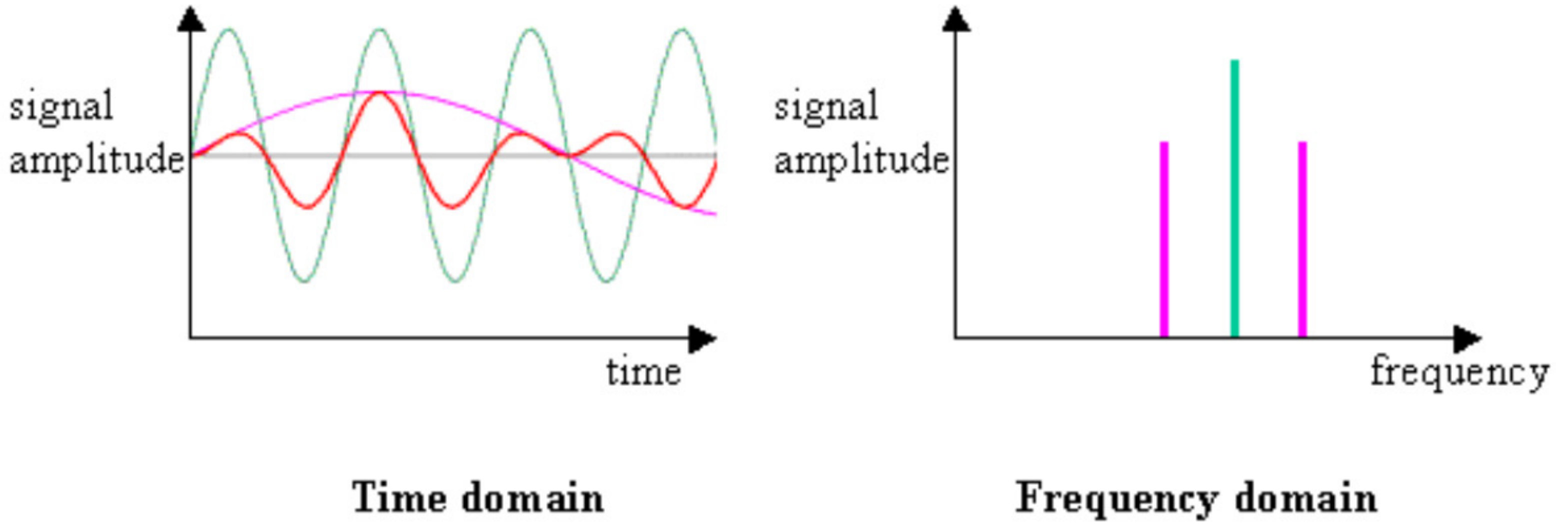
$$s = \frac{a}{4\pi^2 f^2} = \int v \, dt$$



UNITS ACCORDING TO ISO 1000	
MOTION:	m, mm, μm
VELOCITY	m/s, mm/s (eller ms^{-1}, mms^{-1})
ACCELERATION	m/s^2 (ms^{-2}) (NOTE: 1g = 9.81 m/s^2)

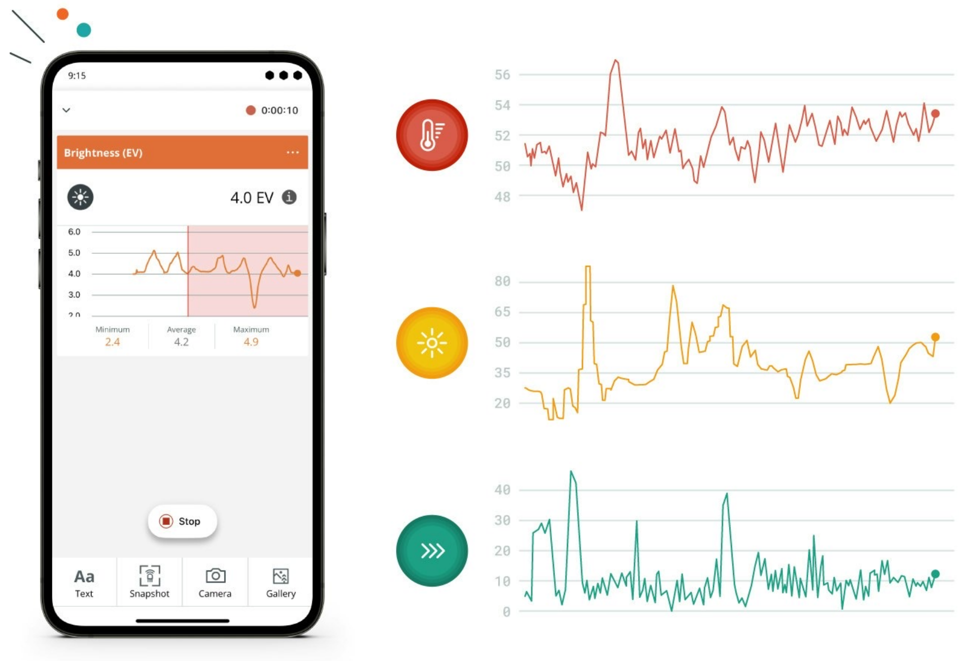
Spectral analysis





Fun with signals!

- https://www.arduino.cc/education/science-journal
- https://github.com/nimRobotics/fft-demo

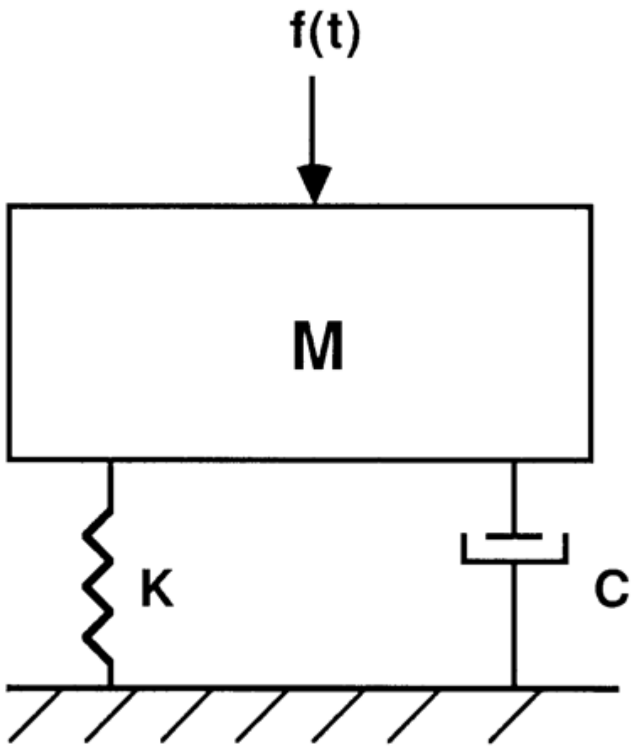


Science Journal

FFT demo

How much whole body vibration exposure is safe?

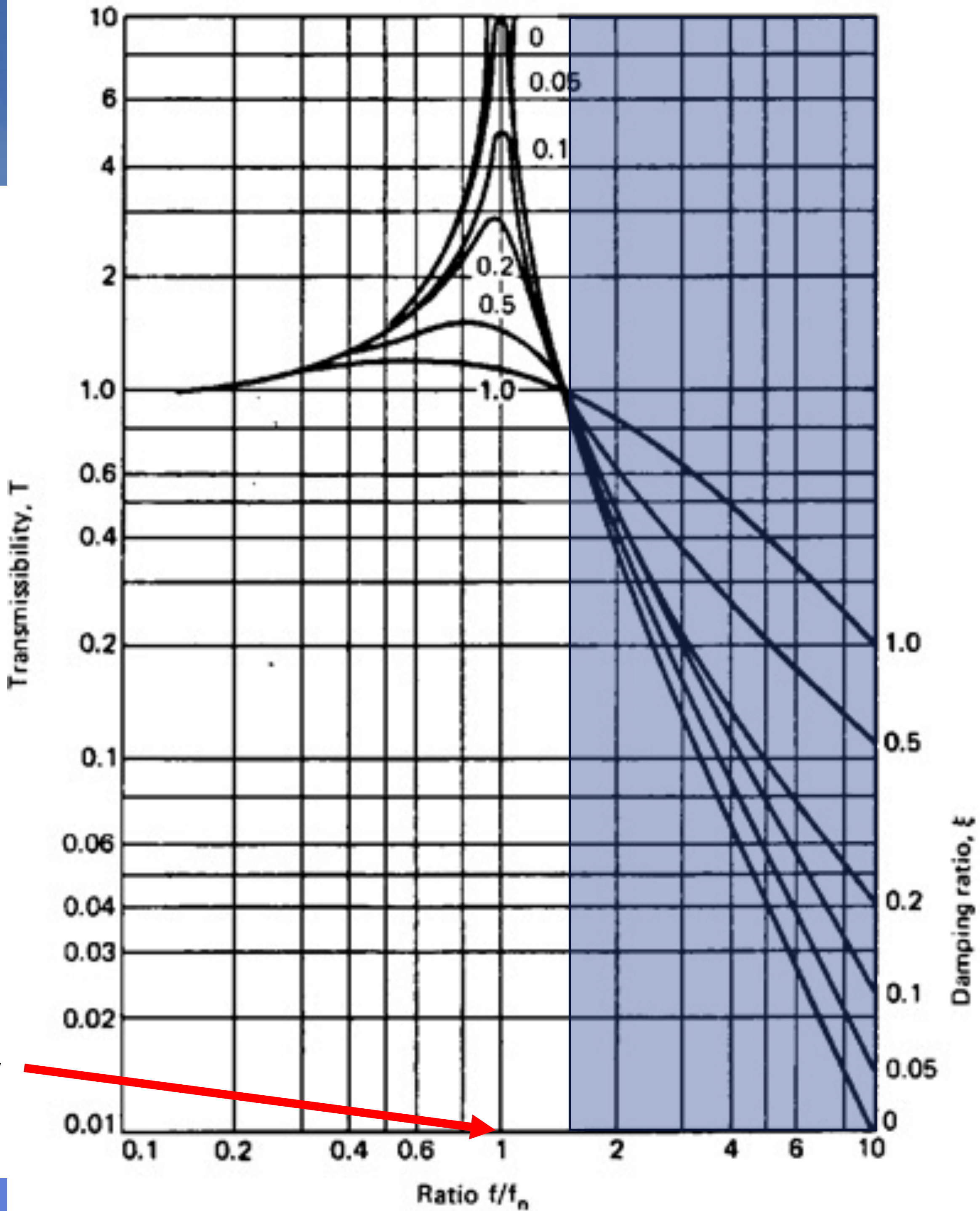
- Mass-spring-damper model



$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{M}}$$

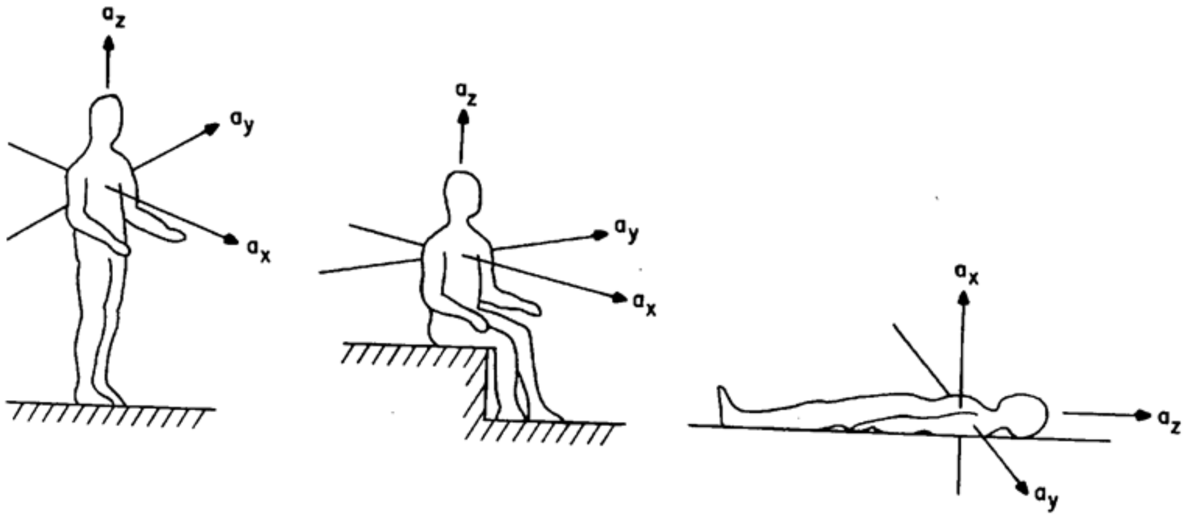
nimrobotics.com/fft-demo/

Resonance

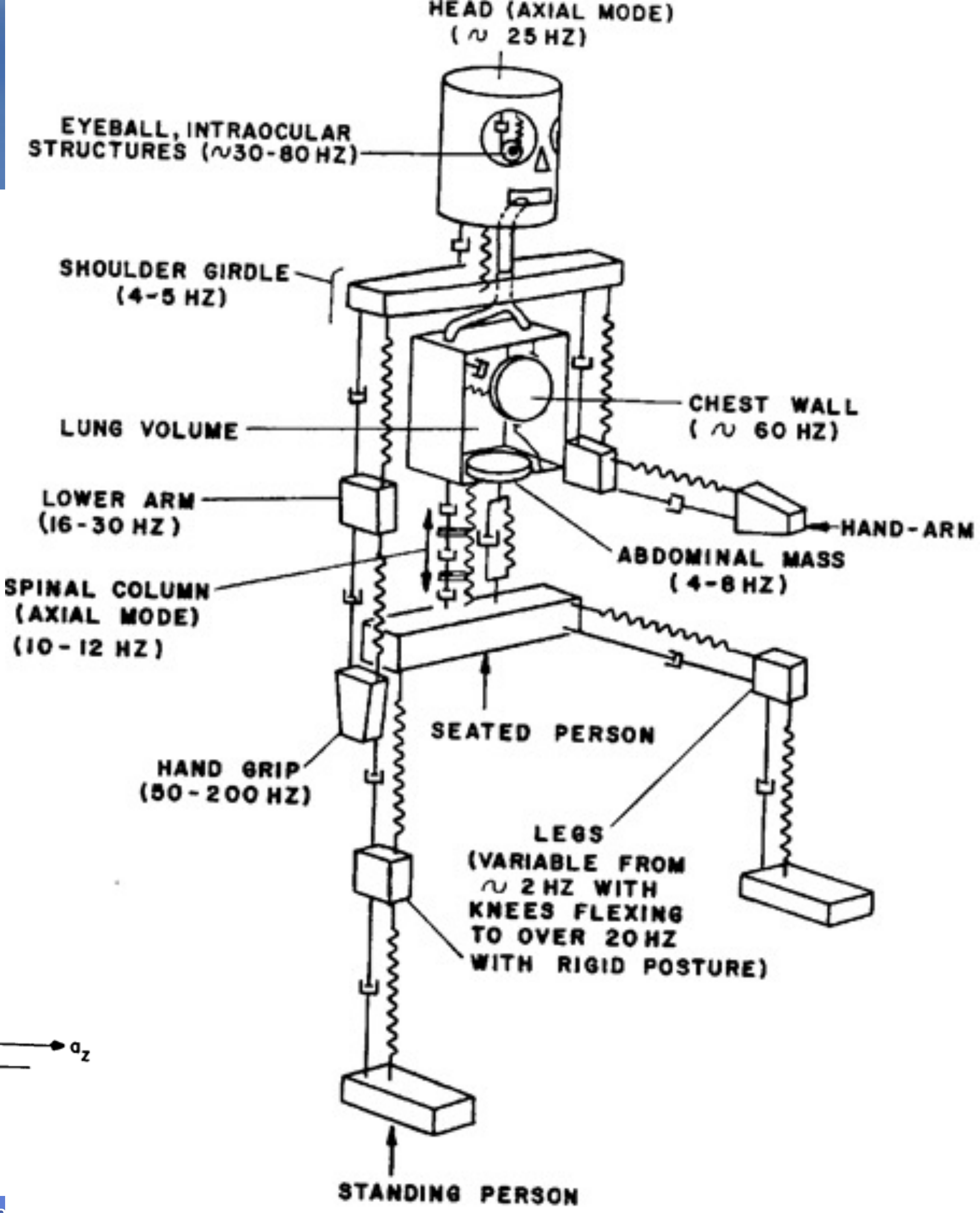


Excitation frequency = natural frequency

Model human



a_z
a_y
a_x
a_z
a_y
a_x
a_x
a_z
a_y

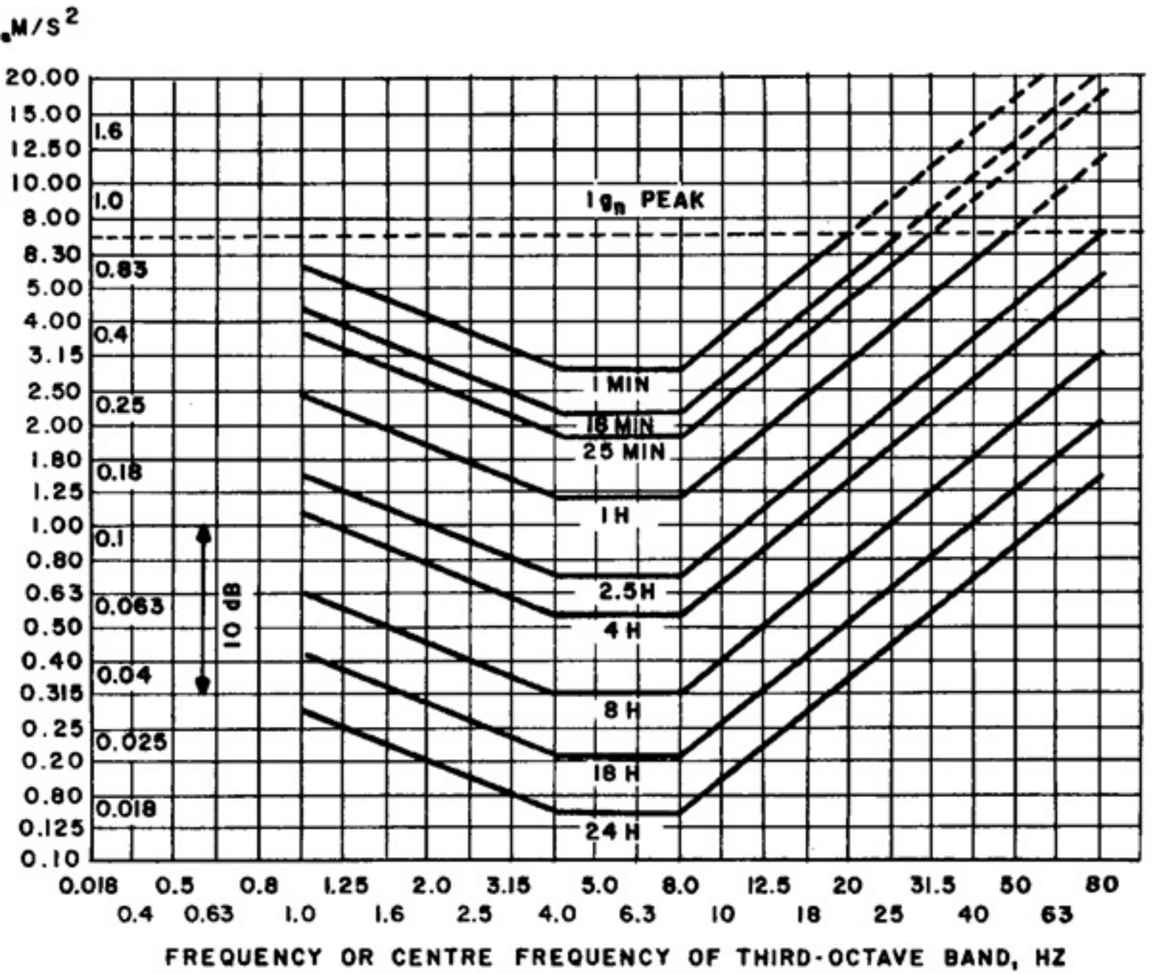


HEAD (AXIAL MODE)
(∼ 25 HZ)
EYEBALL, INTRAOCULAR STRUCTURES (∼30-80 HZ)
SHOULDER GIRDLE (4-5 HZ)
CHEST WALL (∼ 60 HZ)
LUNG VOLUME
LOWER ARM (16-30 HZ)
HAND-ARM
ABDOMINAL MASS (4-8 HZ)
SPINAL COLUMN (AXIAL MODE) (10-12 HZ)
SEATED PERSON
HAND GRIP (50-200 HZ)
LEGS (VARIABLE FROM ∼ 2 HZ WITH KNEES FLEXING TO OVER 20 HZ WITH RIGID POSTURE)
STANDING PERSON

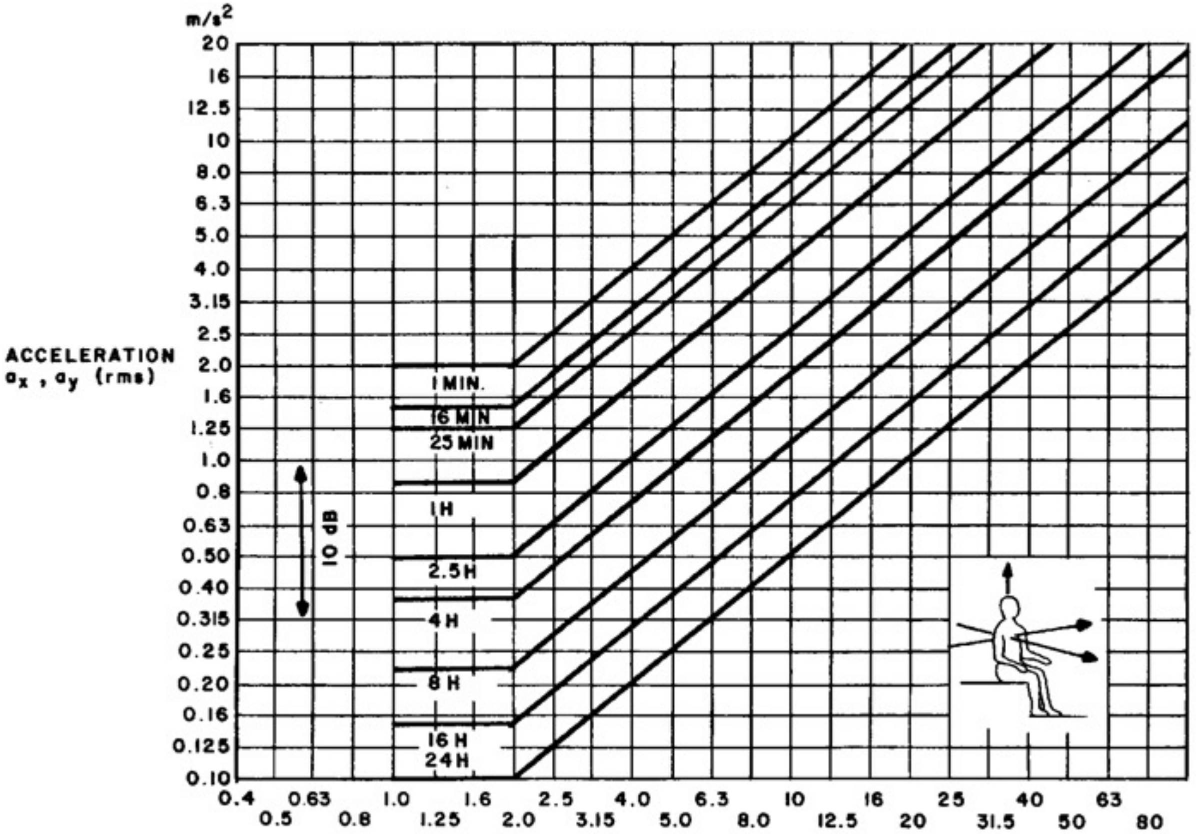
Whole Body Vibration Exposure Guidelines

Standing

TO OBTAIN
-"EXPOSURE LIMITS": MULTIPLY ACCELERATION VALUES BY 2 (6dB HIGHER)
-"REDUCED COMFORT BOUNDARY": DEVIDE ACCELERATION VALUES BY 3,15 (10dB LOWER)



Sitting



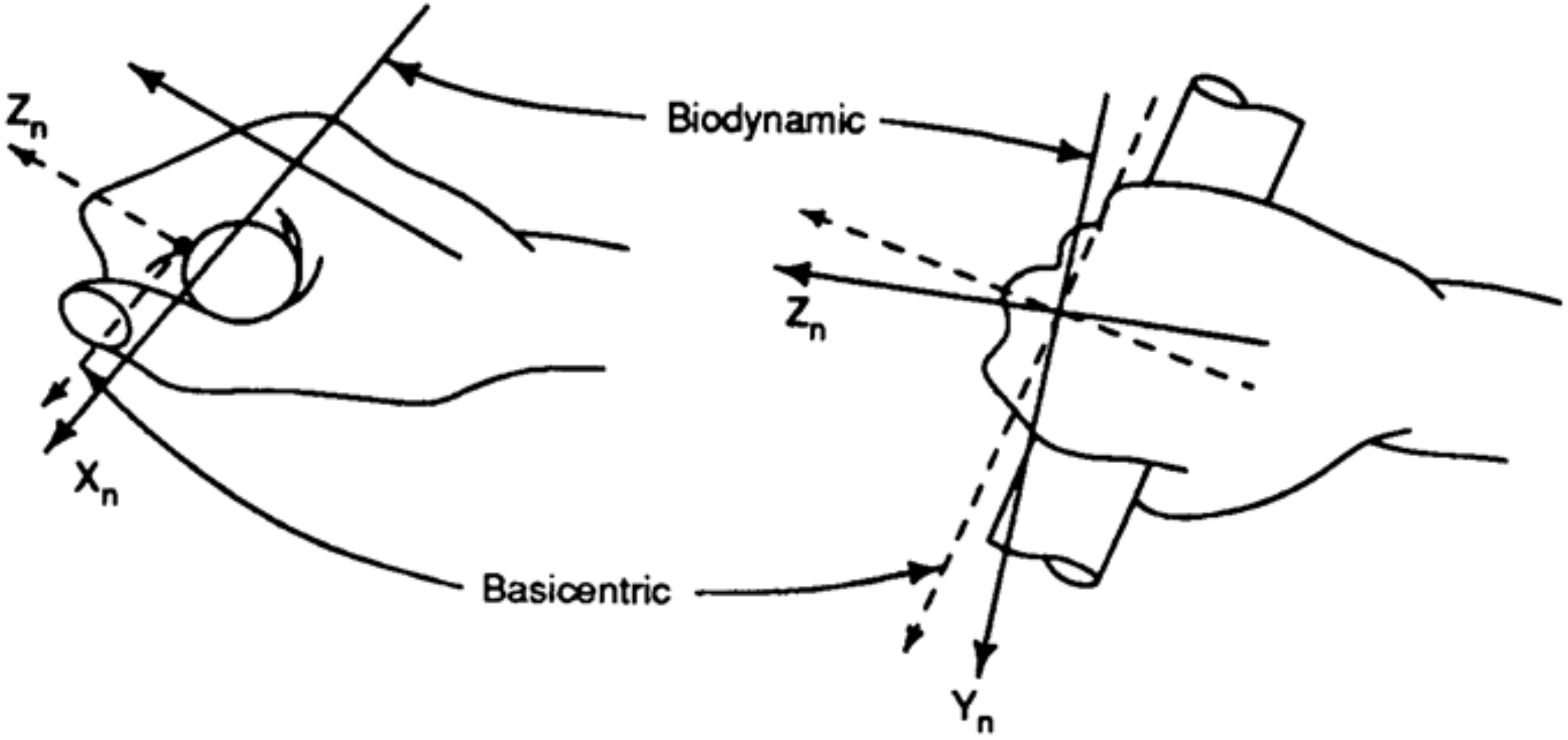
TO OBTAIN :
-"EXPOSURE LIMITS" : MULTIPLY ACCELERATION VALUES BY 2 (6 dB HIGHER):
-"REDUCED COMFORT BOUNDARY" : DEVIDE ACCELERATION VALUES BY 3, 15 (10 dB LOWER).

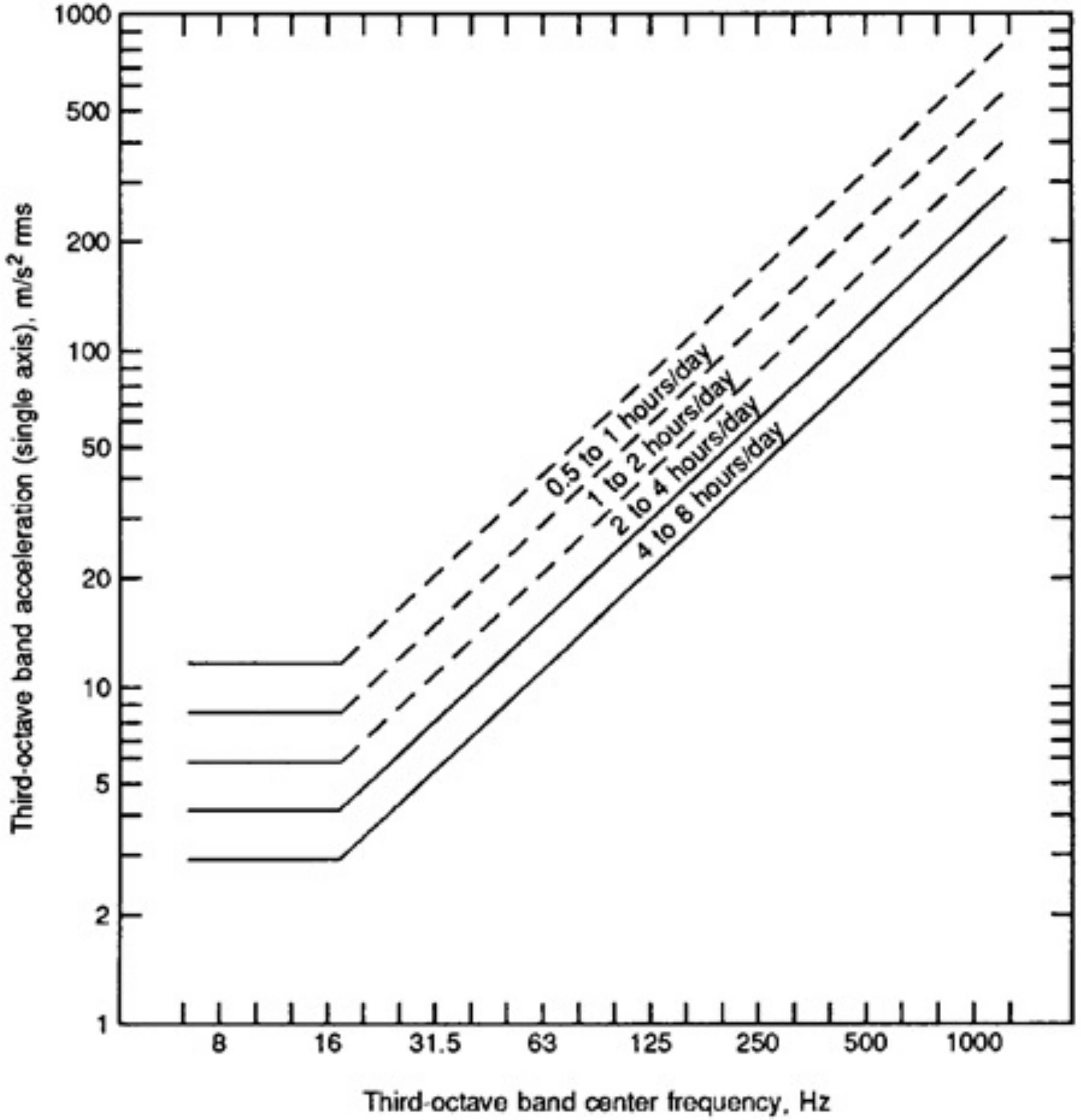
What is hand and arm vibration?

- Circulatory Disturbances
  - Raynaud's Disease

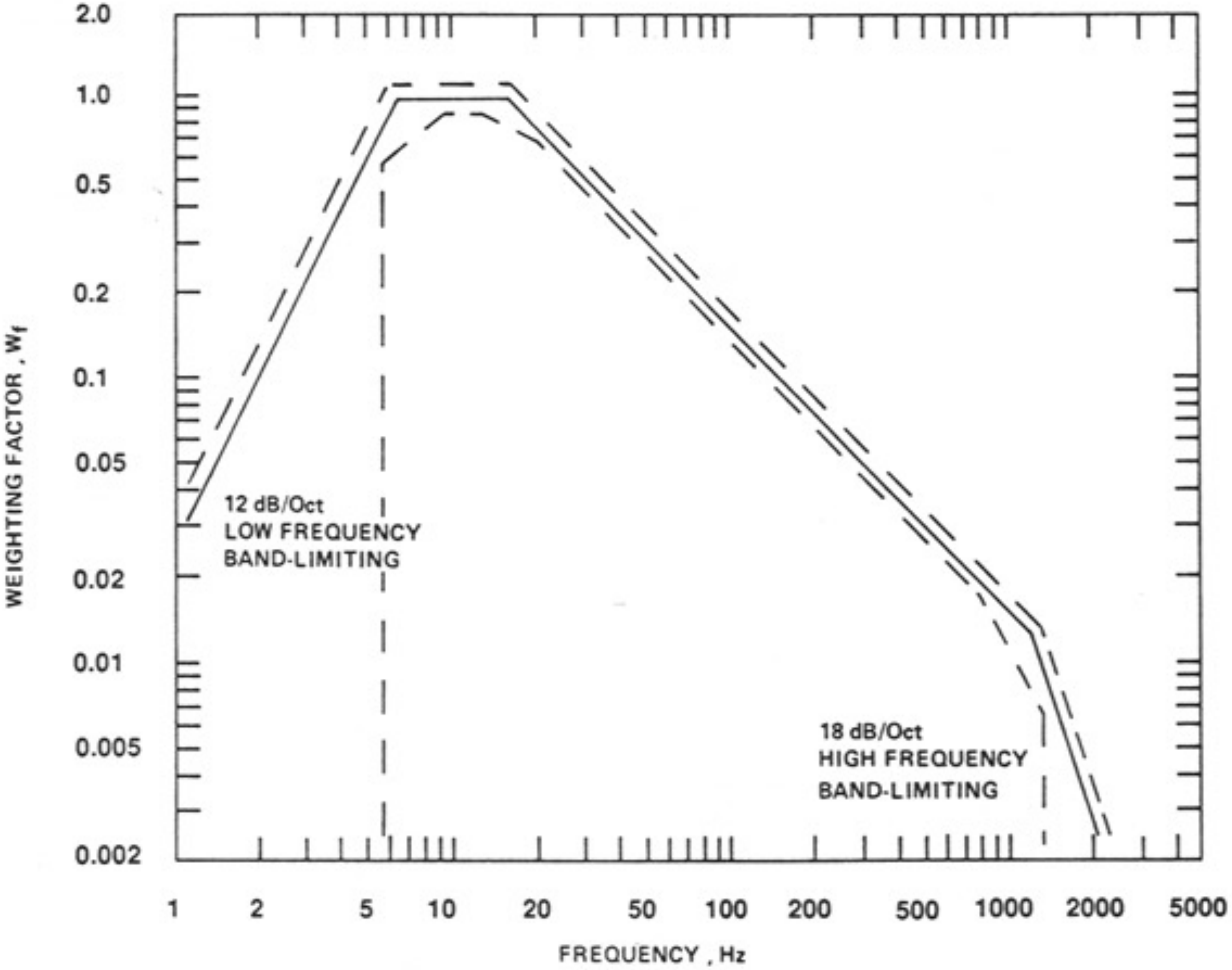
    Vasospasms in the distal fingers causes fingertips to blanch and is precipitated by exposure to cold
- Neuromuscular Disturbances
  - Tonic Vibration Reflex
  - Carpal Tunnel Syndrome

Coordinate systems





Third-octave band acceleration (single axis), m/s² rms
1000
500
200
100
50
20
10
5
2
1
0.5 to 1 hours/day
1 to 2 hours/day
2 to 4 hours/day
4 to 8 hours/day
8
16
31.5
63
125
250
500
1000
Third-octave band center frequency, Hz



WEIGHTING FACTOR, Wf
2.0
1.0
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
12 dB/Oct
LOW FREQUENCY
BAND-LIMITING
18 dB/Oct
HIGH FREQUENCY
BAND-LIMITING
1
2
5
10
20
50
100
200
500
1000
2000
5000
FREQUENCY, Hz

ACGIH Threshold Limit Values for Exposure of the Hand to Vibration in either Xh, Yh, Zh Directions {[rms] acceleration}

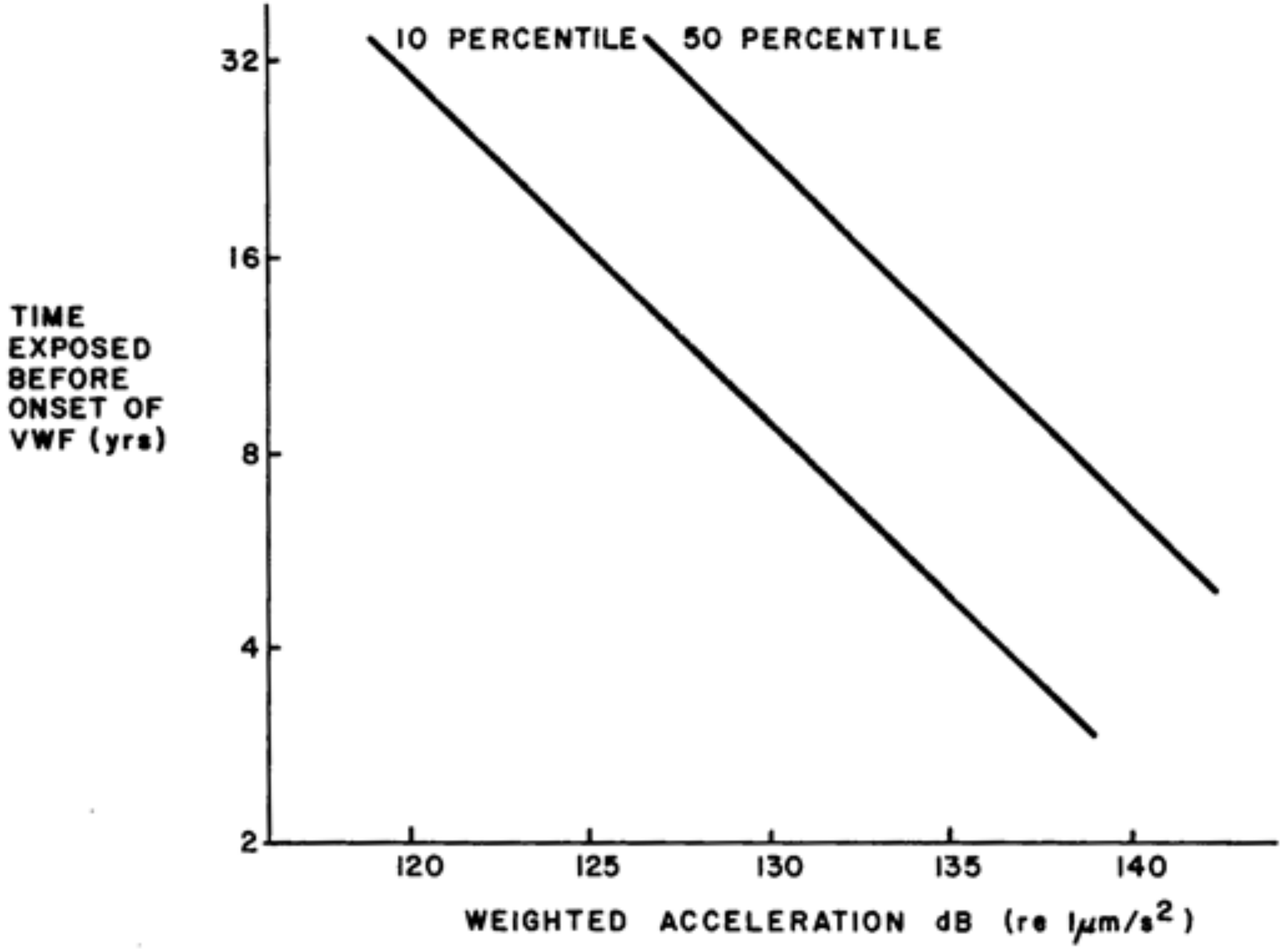
Total Daily Exposure Duration*	Values of the Dominant,** Frequency-Weighted, rms, Component Acceleration which shall not be exceeded*** ak (aKeq)	
	meters/sec./sec.	g
4 hours and less than 8	4	0.40
2 hours and less than 4	6	0.61
1 hour and less than 2	8	0.81
less than 1 hour	12	1.22

* The total time vibration enters the hand per day; whether continuously or intermittently.

**Usually one axis of vibration is dominant over the remaining two axes. If one or more vibration axis exceeds the total daily exposure then the TLV has been exceeded.

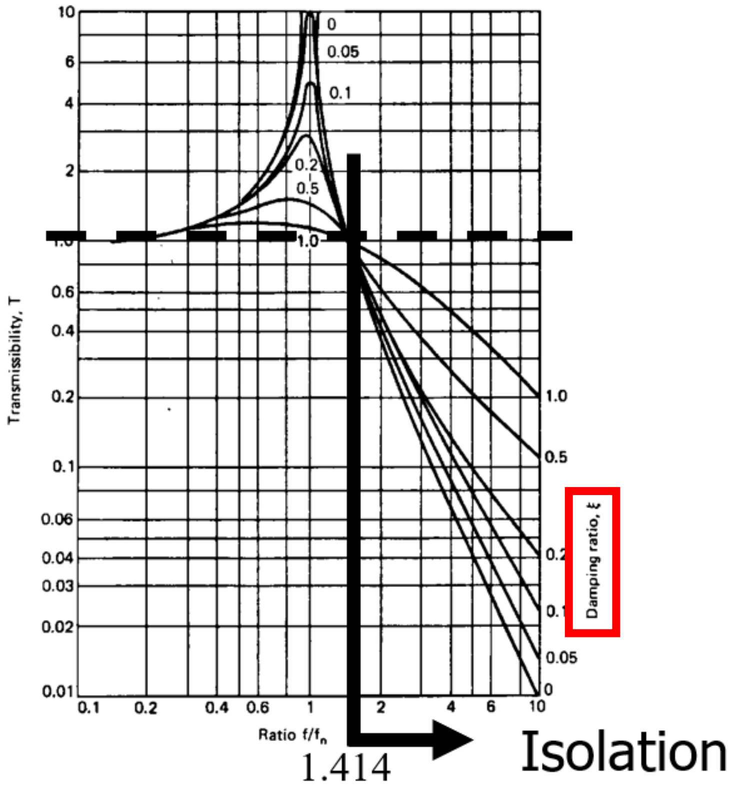
***1 g = 9.81 meters/sec./sec.

Source: ACGIH.

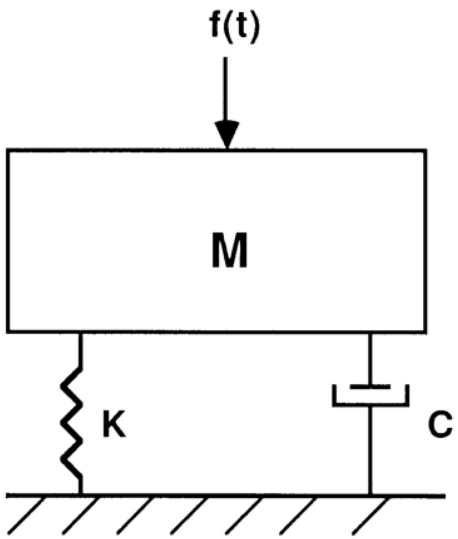

10 PERCENTILE
50 PERCENTILE
32
16
8
4
2
TIME EXPOSED BEFORE ONSET OF VWF (yrs)
120
125
130
135
140
WEIGHTED ACCELERATION dB (re 1μm/s²)

Control

- Source control
  - Equipment design
  - Substitute equipment
  - Tool and equipment maintenance
- Path control
  - Transmissibility and Isolation
  - Damping



$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$



Lecture slides available at

nimRobotics.com/x

Case Study

A factory has various equipment operating throughout the work day. A sound level meter was used to evaluate the sound pressure level (SPL) that an operator is exposed to the SPL of each machine at her workstation.

Machine	SPL (DBA)
A. Washing Machine	105
B. Mill	110
C. Small Press	102
D. Large Press	97

A work sampling study found that the equipment was in operation throughout the 8-hour day as indicated in the table below. Assume that the probability of more than two machines operating together is zero, since there is only one attendant and she can only operate one machine at a time while the other cycles.

Probability (%) Machines are Operating Together

Machine	A	B	C	D
A	20			
B	10	10		
C	15	20	5	
D	5	5	10	0

You are asked to evaluate the operator's exposure to the noise over an eight hour day and to recommend interventions for reducing the noise exposure below acceptable limits. What assumptions will you make? What is the noise exposure for the operator?

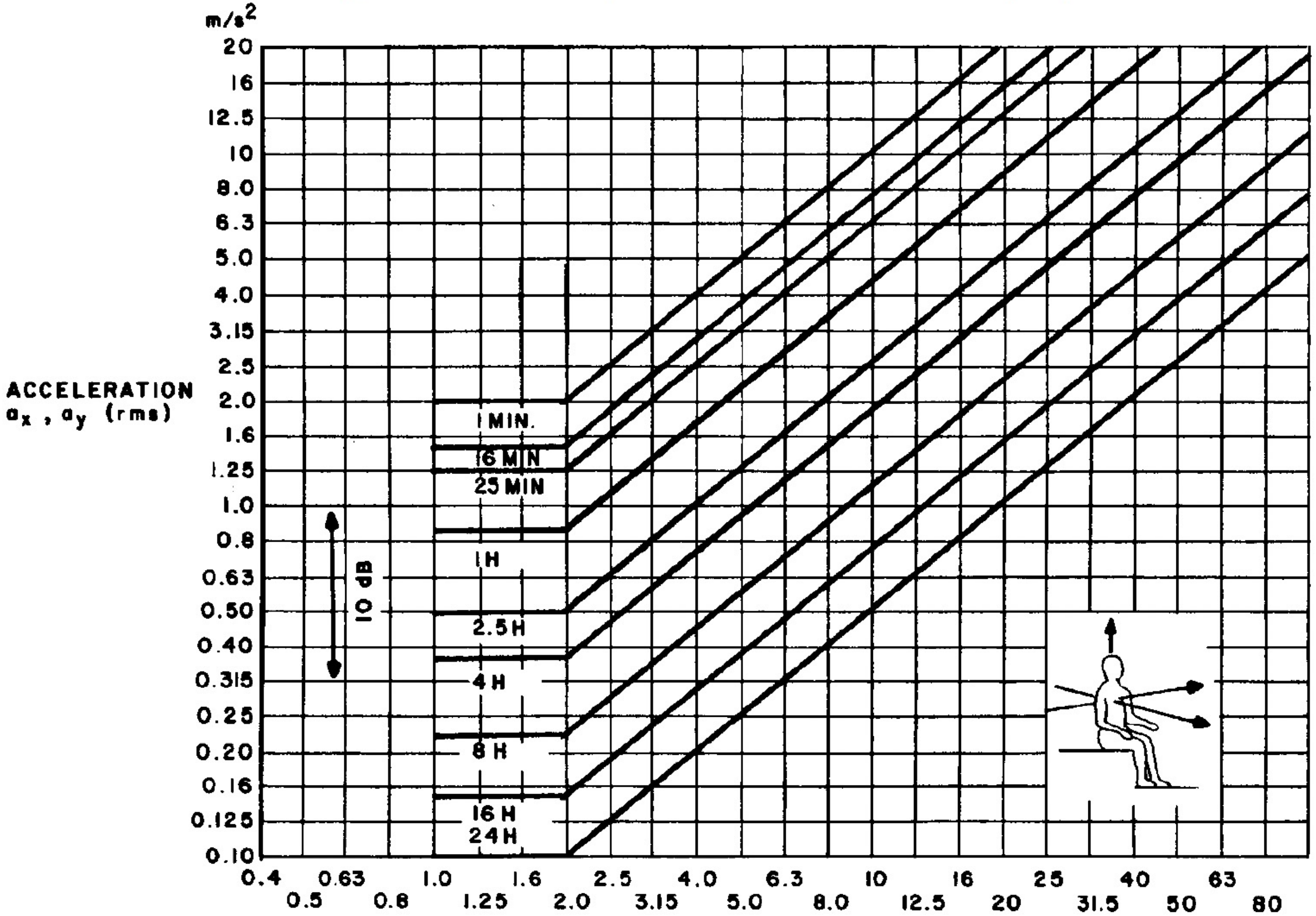
Several interventions are available. This includes personal hearing protection with NRR = 20 dBA, a sound barrier enclosure around each machine that has acoustic transmissibility of 30 dBA, or placing each machine inside a chamber that reduces noise transmission from the outside by 40 dBA but requires the operator to enter the chamber while attending to the machine. What intervention will you select? Are you able to design the intervention to achieve acceptable noise exposure without requiring hearing protection?

Case Study

A crew of construction vehicles were tested for whole-body vibration exposure. The time periods that each machine is operated on a typical day (min) is shown below. The vibration levels in acceleration (m/s^2) is given for each respective vehicle in the x, y and z axes.

			Acceleration (m/s^2)		
Vehicle	Time (min)	Frequency (Hz)	x	y	z
A	230	20	4.5	3.2	5.5
B	356	40	6.5	4.8	8.3
C	400	10	5.3	4.9	16.7
D	168	40	4.6	4.3	7.0
E	378	60	9.1	5.7	5.8
F	264	30	6.7	3.0	4.2

Use the ISO seated whole body vibration guideline (below) for determining if any of these vehicles exceed the <u>fatigue</u> limits. Do any vehicles exceed the safety exposure limits?



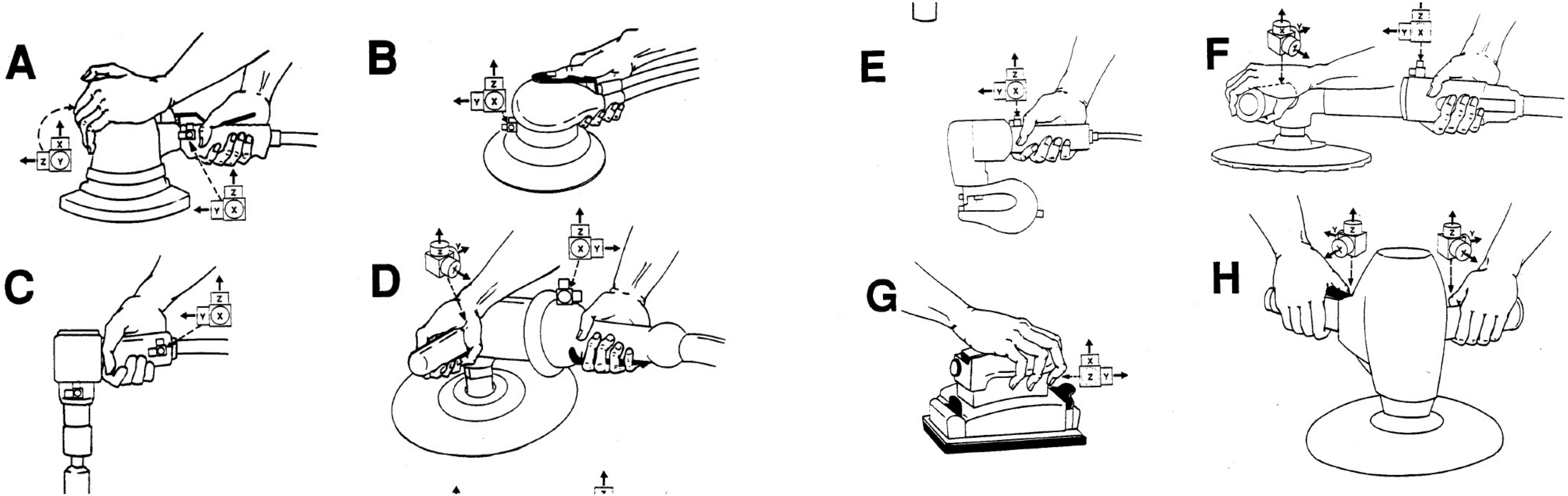
TO OBTAIN :

– "EXPOSURE LIMITS" : MULTIPLY ACCELERATION VALUES BY 2 (6 dB HIGHER):

– "REDUCED COMFORT BOUNDARY" : DEVIDE ACCELERATION VALUES BY 3, 15 (10 dB LOWER).

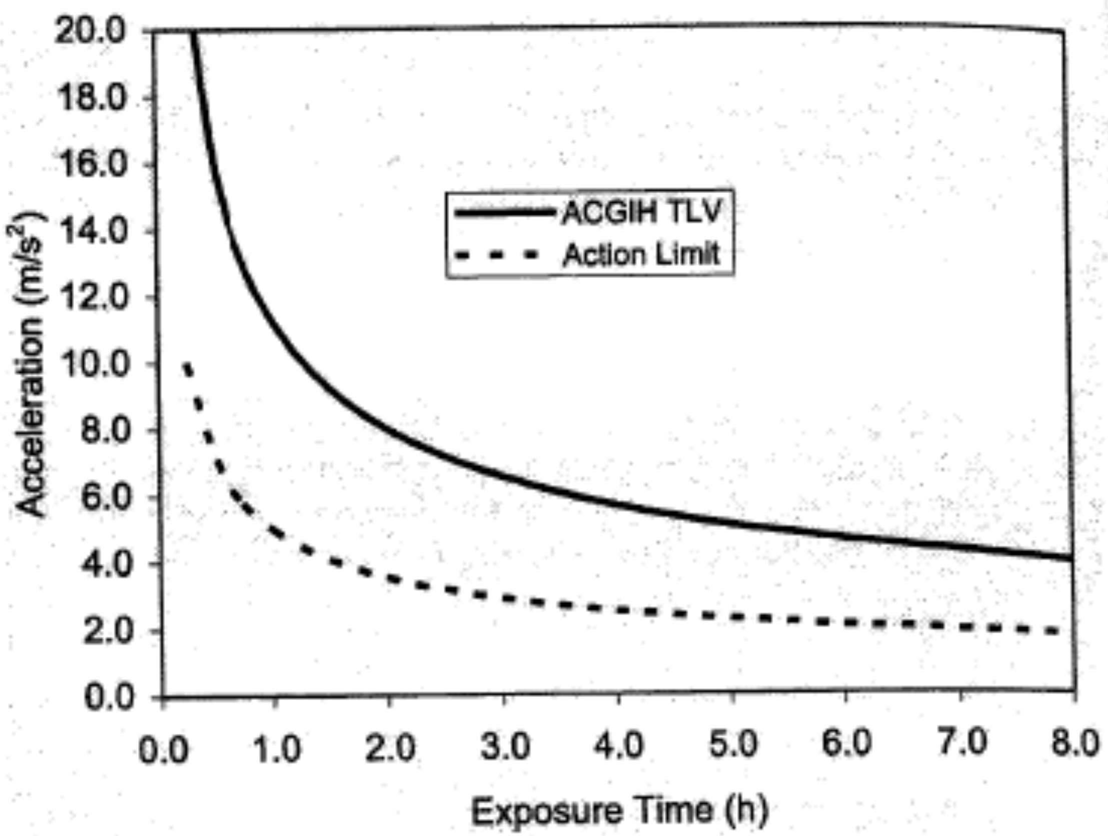
Case Study

Handle vibration levels for a variety of power hand tools used in a factory were measured. The tools are shown below along with the corresponding vibration data. Evaluate the ACGIH TLV for hand and arm vibration and the ANSI hand and arm vibration exposure limits for each of these tools to determine the maximum exposure time permissible. What assumptions did you make? Do the two guidelines agree?



Summary of Frequency-Weighted Individual Axis and Total Vibration

Tool Description	Handle	No. of Hands	Abrasive	Frequency-Weighted Continuous RMS Acceleration (m/s²) Axis X	Y	Z	Total
Hand grip orbital sander	main	1	100 grit	17.7	21.3	67.8	73.2
		2	100 grit	6.9	16.6	40.9	44.6
		1	80 grit	23.5	29.4	72.5	81.7
		2	80 grit	16.5	26.1	38.9	49.6
	body	2	100 grit	21.4	23.9	32.3	45.5
		2	80 grit	27.1	26.8	30.1	48.5
Palm grip orbital sander	body	1	320 grit	20.0	11.3	20.8	30.9
	body	1	100 grit	18.0	10.4	25.3	32.7
	body	1	80 grit	25.4	15.3	35.6	46.3
Impact wrench	grip	2	locked	17.9	10.5	12.2	24.0
	body	2	spindle	29.3	20.5	35.3	50.3
Heavy duty right angle sander	main	2	80 grit	2.7	2.9	1.9	3.9
	dead	2	80 grit	3.6	4.3	4.5	7.2
	main	2	grinding disc	23.0	13.3	13.4	29.7
	dead	2	grinding disc	8.9	20.5	19.3	29.5
Trimming shear	main	1	blade	5.0	5.8	5.4	9.4
Light duty right angle sander	main	2	fine disc	1.9	1.1	1.1	2.4
	dead	2	fine disc	10.8	16.4	14.0	24.1
Jitterbug sander	body	1	230 grit	51.5	13.5	51.1	73.8
Vertical polisher	right	2	polishing	7.0	4.1	5.6	9.8
	left	2	pad	8.8	7.3	32.9	34.8



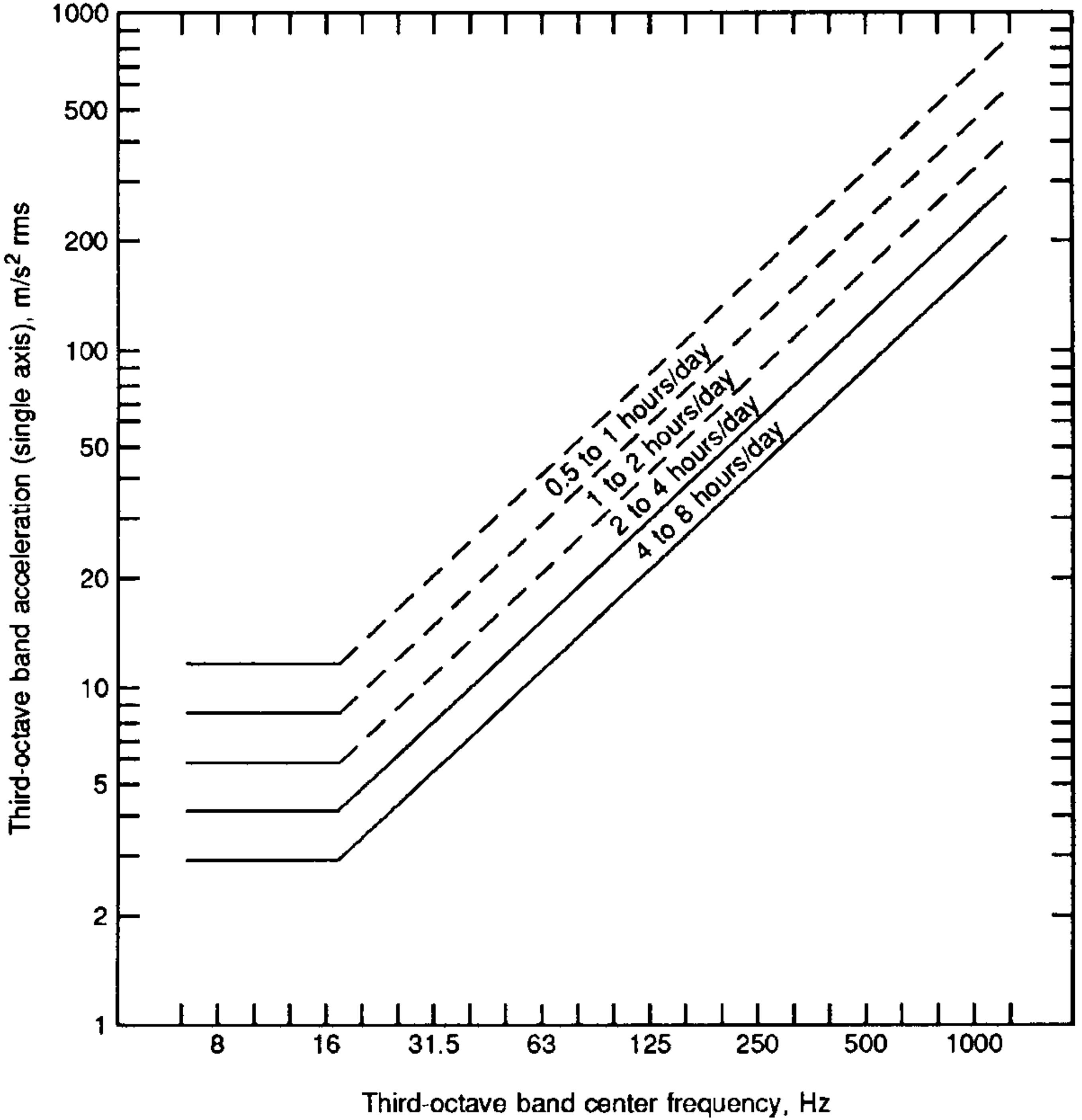
ACGIH Threshold Limit Values for Exposure of the Hand to Vibration in either Xh, Yh, Zh Directions {[rms] acceleration}

Total Daily Exposure Duration*	Values of the Dominant,** Frequency-Weighted, rms, Component Acceleration which shall not be exceeded*** ak (aKeq)	
	meters/sec./sec.	g
4 hours and less than 8	4	0.40
2 hours and less than 4	6	0.61
1 hour and less than 2	8	0.81
less than 1 hour	12	1.22

* The total time vibration enters the hand per day; whether continuously or intermittently.
**Usually one axis of vibration is dominant over the remaining two axes. If one or more vibration axis exceeds the total daily exposure then the TLV has been exceeded.
***1 g = 9.81 meters/sec./sec.
Source: ACGIH.

Summary of Dominant Frequency and Corresponding Individual Axis Acceleration Magnitude for Tools Tested

Tool Description	Handle	No. of Hands	Abrasive	Frequency (Hz)	Magnitude (m/s^2) Axis X	Y	Z
Hand grip orbital sander	main	1	100 grit	90	50	60	190
		2	100 grit	90	30	70	220
		1	80 grit	90	70	50	120
		2	80 grit	90	40	90	110
	body	2	100 grit	90	90	110	140
		2	80 grit	90	60	80	90
Palm grip orbital sander	body	1	320 grit	150	120	70	40
	body	1	100 grit	150	120	70	170
	body	1	80 grit	150	115	60	120
Impact wrench	body	2	locked spindle	50	10	10	10
Heavy duty right angle sander	main	2	80 grit	45	5	2	2
	dead	2	80 grit	45	5	6	6
	main	2	grinding disc	80	90	70	40
	dead	2	grinding disc	80	40	50	80
Trimming shear	main	1	blade	35	6	15	10
Light duty right angle sander	main	2	fine disc	70	3	2	1
	dead	2	fine disc	70	2	6	7
Jitterbug sander	body	1	230 grit	100	290	110	130
Vertical polisher	right	2	polishing pad	100	20	20	20
	left	2		100	30	20	150



Third-octave band acceleration (single axis), m/s² rms
1000
500
200
100
50
20
10
5
2
1
0.5 to 1 hours/day
1 to 2 hours/day
2 to 4 hours/day
4 to 8 hours/day
8
16
31.5
63
125
250
500
1000
Third-octave band center frequency, Hz

Thanks

Questions?

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