3M Occupational Health & Environmental Safety Division

Introduction to Sound & Noise Measurement

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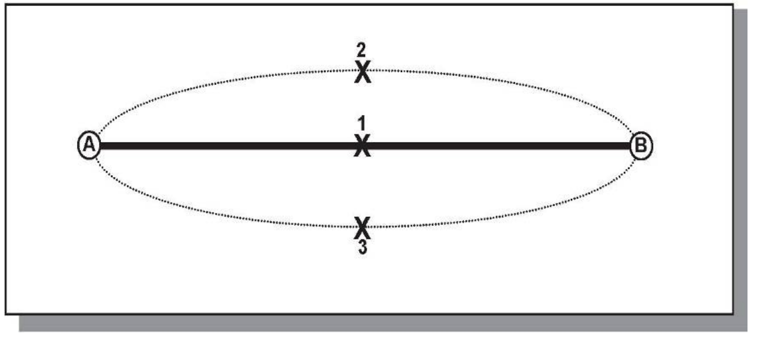
Introduction to Sound & Noise Measurement

- Terminology
- Instrumentation
- Measurement Issues
- Standards and Regulations

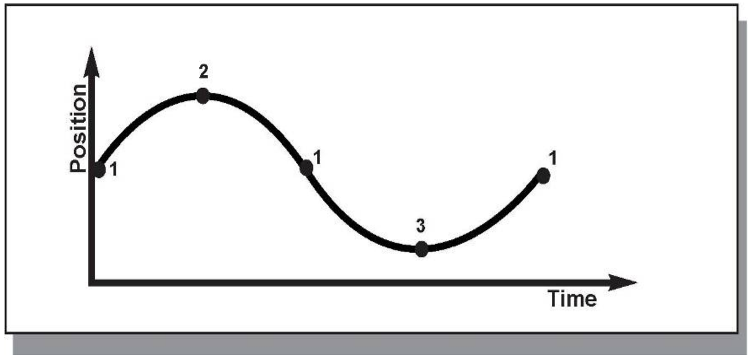
Basics – Definition of a Sound

Here is a diagram representing a string attached at points A and B. At position (1), the string is in its normal resting position. When the string is stretched to position (2) and released, elasticity is high and it will start to return to its resting position (1). As it reaches (1), inertia (tendency to continue in a fixed direction) is high and it will continue traveling through (1) to (3).



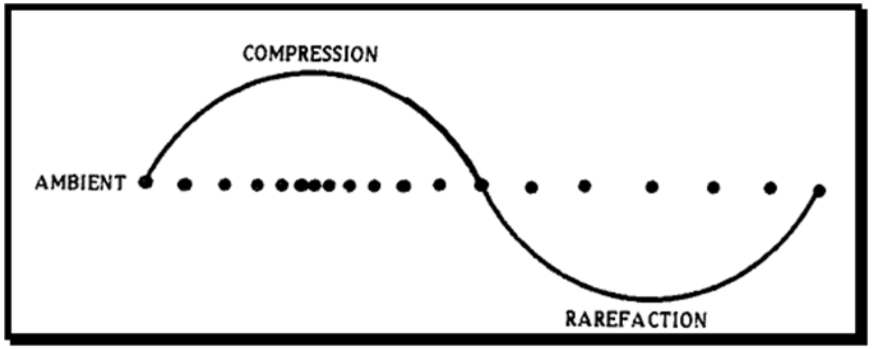
Basics – Definition of a Sound Continued

When the string has traveled from (1) to (2) to (1) to (3) and back to (1), one complete cycle has occurred. This graph shows this cycle as a function of time; the curve drawn is referred to as a sine wave.



Basics – Definition of a Sound Continued

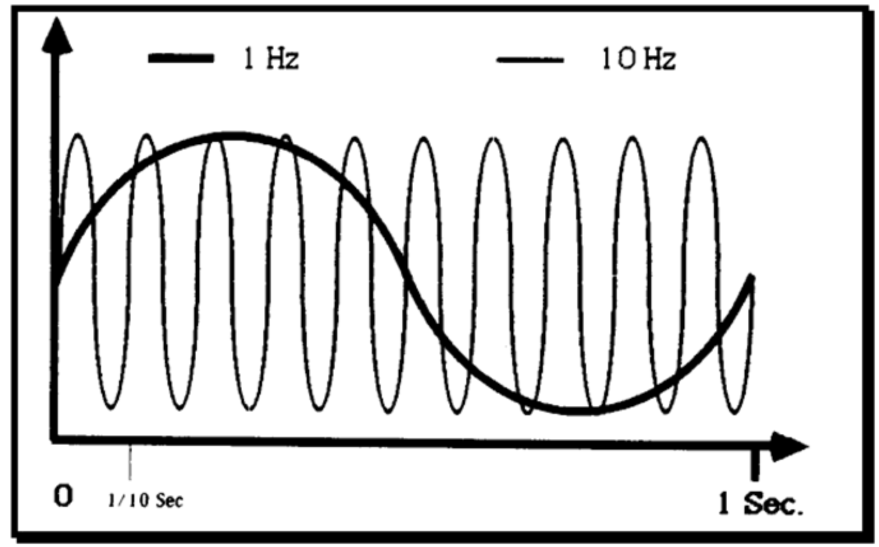
When sound travels in air, it creates alternating positive and negative pressures (compressions and rarefactions) of the air molecules. This graph shows how air molecules are compressed and rarefied as a function of the sound pressure. It is these changes in pressure that is measured by a sound level meter (SLM), octave band analyzer (OBA), real time analyzer (RTA) and noise dosimeter. While many aspects of a sound can be measured and analyzed, two are most commonly considered… how many cycles are completed in a period of time, and how much pressure is created.



Basics – Sound Metrics

Frequency

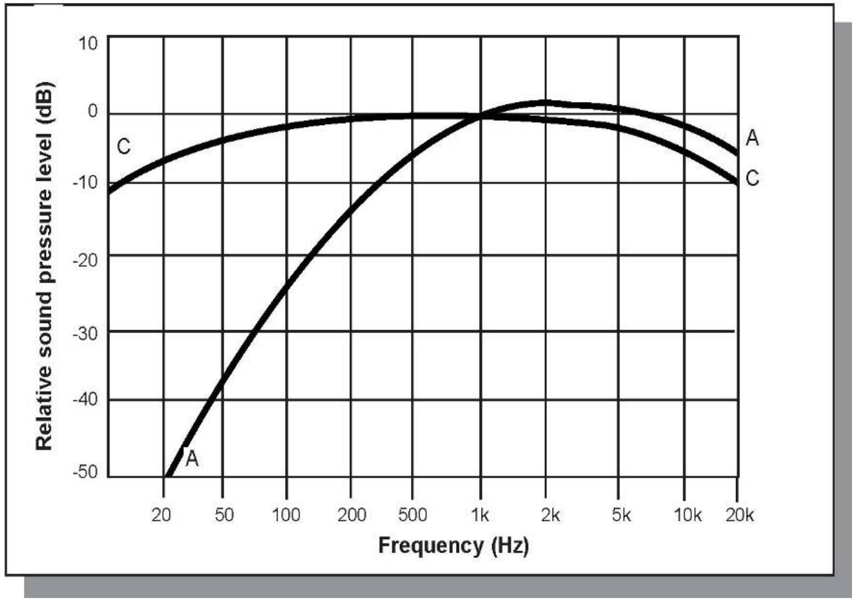
When a sound is transmitted in air, the air molecules will be compressed and rarefied. The rate of this movement can vary, and the number of times per second a cycle pattern repeats itself defines a sound's frequency or cycles per second (CPS). When a tuning fork is vibrating it will produce a sound by resonating in a repetitive pattern. The unit of measurement for frequency is hertz (abbreviated Hz). This drawing depicts two sine waves on the same graph. The time duration for both signals shown is 1 second. One sine wave completes one cycle within that second and the other completes 10 cycles. The frequency of each sine wave is 1 and 10Hz respectively.



Basics – Sound Metrics

Frequency Weighting

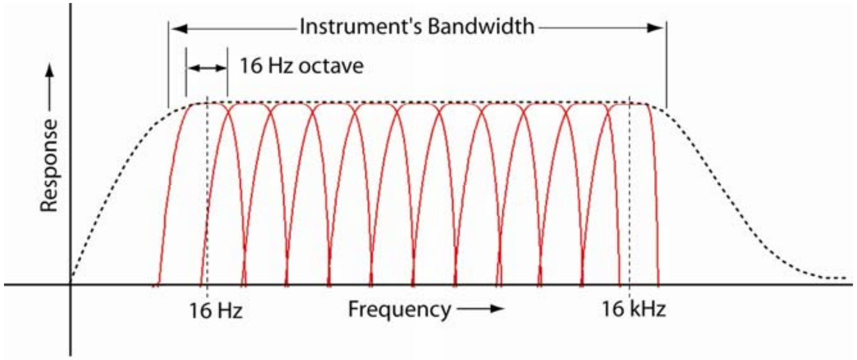
When the sound exposure for hearing conservation is to be measured, the instrument used typically must have a built in frequency filtering network so that measured levels relate to the risk for damage to hearing. This filtering network is characterized by reduced sensitivity at frequencies below 500 Hz and above 4000 Hz, see curve “A”. This filter is called an “A” filter (or “A” weighting). The “C” curve which is also shown is more linear. “C” weighting is often used to assess machinery or for community noise applications, and may also be used in the evaluation of hearing protectors.



Basics – Sound Metrics

Octave Band Filters

The spectrum of audible frequencies can be divided into octaves. An octave is the interval between two frequencies having a base ratio of two (one sound being twice or half the frequency of the other). For example, the difference between 1000 and 2000 Hz is one octave. There are 7+ octaves on a standard piano keyboard, and for every 8 white keys the frequency doubles - the tone is one octave higher. A SLM with octave band filters (Octave Band Analyzer – OBA) has the capability of measuring sound levels in a selected frequency band while simultaneously excluding sounds outside of that band. This drawing shows a set of graphs for an octave band filter. This allows for better or finer definition when measuring the sound level as a function of frequency beyond that available with A or C weighting.



Basics – Sound Metrics

Octave Band Analysis

Here is an example of an octave band study performed to determine the application of noise controls on the sound source. It is done to identify the strongest frequency signal present so that noise control efforts can be focused on that signal.

Date: October 18, 2006

Instruments & S/N:
- ☑ SoundPro DL #CD6040002
- ☑ Quest QC-20 #QF6040003

Calibrated: January 20, 2007

TEST #1 #2

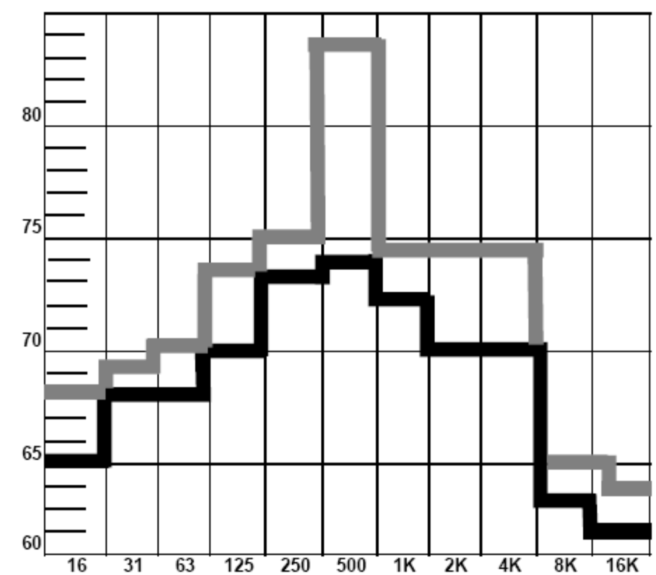
By: R.J.W.

Project: Compressor motor 3ft from shaft axis perpendicular

Comments:

Graph Key
#1 = Before installing Engineering Controls
#2 = After installing Engineering Controls

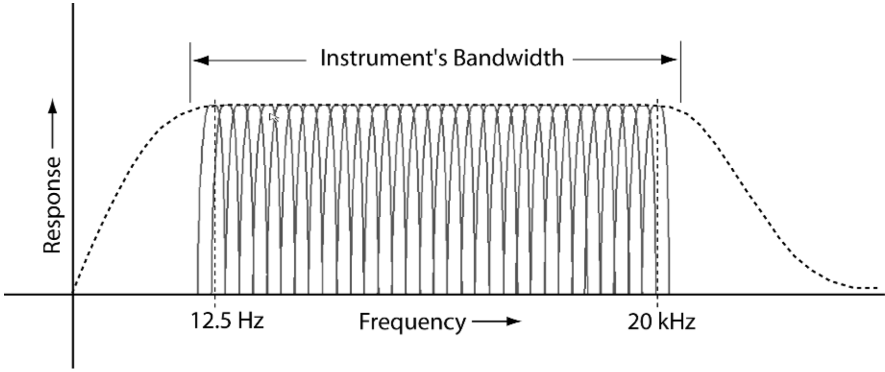
Test	#1	#2
DBA	84	77
dB LIN	84	78
16 Hz	68	65
31 Hz	69	68
63 Hz	70	68
125 Hz	74	70
250 Hz	75	73
500 Hz	83	74
1 k	74	73
2 k	74	70
4 k	74	70
8 k	65	62
16 k	63	61



Basics – Sound Metrics

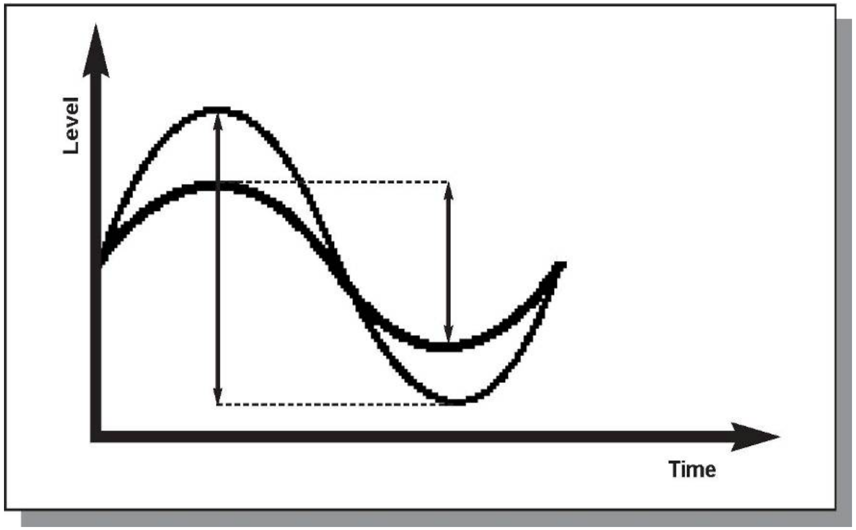
1/3rd Octave Bands

When even finer frequency definition is needed, 1/3rd octave bands can be used. This take sound range and divides it into 33 bands. This is not typically used in hearing conservation, but can be used for machine performance and maintenance applications and for product testing. When an Octave Band Analyzer is used for frequency study, each filter must be measured sequentially. If a Real Time Analyzer is used for either Octaves or 1/3rd octaves, all the frequencies are measured simultaneously, so the results are achieved more quickly and all the results are synchronized.



Basics – Sound Metrics
decibels SPL

The intensity of sound is measured in decibels, or tenths of a Bel, Sound Pressure Level (dB SPL). The decibel scale is a logarithmic function. One reason for using a logarithmic scale to measure sound is because the ratio between the threshold of hearing and threshold of pain in the human ear if measured in true energy is 100,000,000,000,000 times. The same range using the decibel scale is 0 - 140 dB. In noise measurement decibels are referenced to 20 micro Newton/m2. When sound is measured using "A" or "C" weighting the level is noted as in dBA or dBC. This drawing shows two sine waves with the same frequency, but different intensities.



Basics – Sound Metrics
decibels SPL

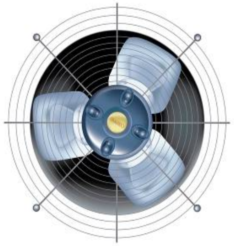
Here are some sources and their typical respective sound pressure levels in decibels.

140	Super siren. Jet airplane takeoff at 50 feet.
130	Approximate threshold of pain in the human ear.
120	Jet airplane takeoff at 200 feet.
110	Riveting machine. Chain Saw.
100	Area around electric furnace.
90	Boiler room. OSHA permissible exposure level (PEL).
80	Pneumatic drill at 50 feet.
70	Speech at 1 foot.
60	Background in large retail store. Speech at 3 feet.
50	Private business office. Typical home.
40	Quiet residential area.
30	
20	Background in motion picture studio.
10	
0	Average threshold of hearing, 1 - 4kHz.

Basics – Sound Metrics

Changing Sound Levels

The characteristics of noise are commonly divided into three groups: continuous, variable, and impulsive. Continuous noise is defined as noise of a constant level (+/-2 dB of fluctuation or less). Impulsive (explosion) or impact (surface to surface contact) noise has duration of less than one second. Variable noise is a signal which varies in intensity in durations exceeding one second and may last minutes or even hours.



A fan is an example of a continuous noise source

An explosion or gunshot are examples of an impulsive noise

A hammer striking a nail would create an impact noise signal

Basics – Sound Metrics

Exchange Rate

Exchange Rate (ER)

- *Also known as the Doubling Rate, refers to how the sound energy is averaged over time. Using the decibel scale, every time the sound energy doubles, the measured level increases by 3 dB. For every increase of 3 dB in the time weighted average, the measured dose would double.*

- *Commonly used exchange rates include 3, 4 and 5 decibels. Which exchange rate is to be applied is determined by the regulation being applies, for example OSHA, MSHA, the European Union, US Department of Defense, etc.*

L_EQ referred to as Level Equivalent

The true equivalent sound level measured over the run time based on a 3 dB exchange rate. Rather than a point in time like a sound pressure level, the L_EQ is an averaged level derived from multiple sound pressure levels that have been measured and logarithmically averaged.

Basics – Sound Metrics

Sound Level Averaging

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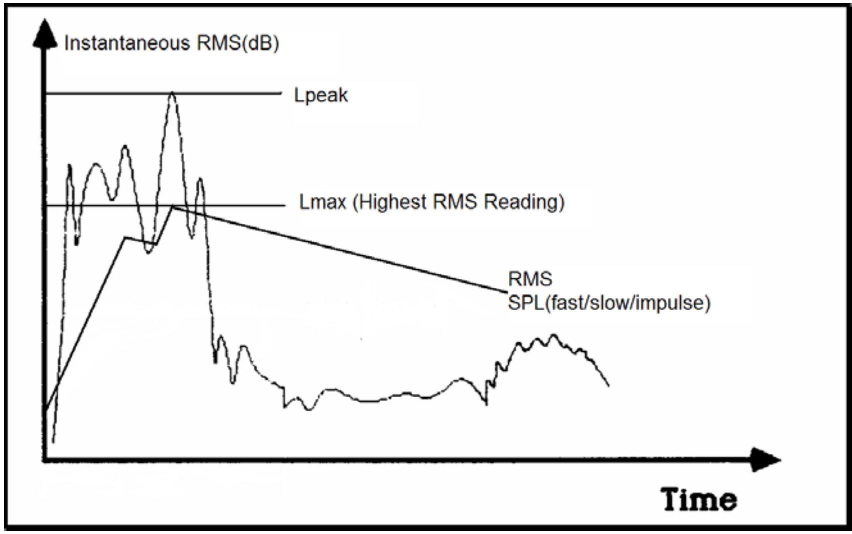
L_AV referred to as Level Average

Average sound level measured over the run time typically based on an exchange rate **other** than 3, such as 4 or 5 dB.

Basics – Sound Metrics

Response Time

The response time is a standardized exponential time weighting of the input signal according to fast (F), slow (S) or impulse (I) time response relationships. Time response can be described with a time constant. The time constants for fast, slow and impulse responses are 1.0 seconds, 0.125 seconds and 0.35 milliseconds, respectively. Also, for very short duration signals, a peak response may be used. Most hearing conservation regulations focus on slow response.



Basics – Sound Metrics

Frequency Weighting

L_Mn

Minimum SPL. Lowest SPL measured over a time interval.

L_Mx

Maximum SPL. Highest SPL measured over a time interval.

Basics – Sound Metrics

Time Weighted Average

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The equivalent constant sound pressure level that if present over an 8-hour interval would produce the same exposure to sound as an exposure measured over a run time sampling interval (Rtime). A TWA assumes an eight hour run time even if the actual sampling period was less than or more than eight hours. The TWA when applied to noise is notably different from TWA measurements for other typical exposures measured for industrial hygiene and environmental studies.

Basics – Sound Metrics

Dose

While a Time Weighted Average is a decibel based measure, a dose is a percentage of allowable exposure. Related to the Criterion Level, a dose reading of 100% is the maximum allowable exposure to accumulated noise. For OSHA, 100% dose occurs for an average sound level of 90 dB over an 8 hour period (or any equivalent exposure). This relationship varies according to the regulation being applied. A TWA of 90 dB is the equivalent of 100% dose in the OSHA scheme. The dose will double (halve) every time the TWA increases (decreases) by the Exchange Rate.

Basics – Sound Metrics

Calculating Dose

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$$100 \times (C_1/T_1 + C_2/T_2.....C_N/T_N) = \%Dose$$

Where C is the actual time exposed at a sound level

- and -

T is the allowable time for that sound level

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Basics – Sound Metrics
Understanding Dose

- **Example 1**: For an Exchange Rate of 5 dB, suppose the TWA is 100 dB. The dose would double for each 5 dB increase over the Criterion Level of 90 dB. The resulting dose is therefore 400%. If the TWA was instead equal to 80 dB then the dose would halve for each 5 dB below the Criterion Level. The resulting dose would be 25%.

Basics – Sound Metrics

Understanding Dose

- Example 2: If a 0.5 hour sample results in 9% dose and the workday is 7.5 hours long, then the dose for the full workday would be a 135% dose (7.5 / 0.5 x 9%). This is computed making the assumption that the sampled noise will continue at the same levels for the full 7.5 hour workday.

Basics – Sound Metrics
Understanding Dose

Assume the following noise levels occur in a workplace

1 hour at 90 dB　　3 hours at 85 dB

2 hours at 95 dB　　1 hour at 100 dB

The resulting dose would be calculated as follows

100 x (1/8 + 3/16 + 2/4 + 1/2) = %Dose

100 x (21/16)

100 x 1.31

131 % Dose

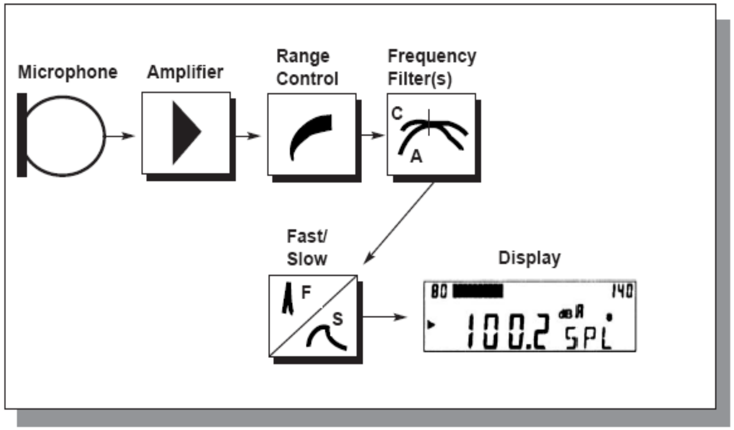
Basics – Sound Metrics

A Review

Term	Unit of Measure	Purpose
Criterion	decibel	The level set by regulation, that if you were exposed to it on average for eight hours, would result in a maximum allow-able exposure.
Threshold	decibel	The level set by regulation, below which all measured values are assigned a value of zero
Exchange Rate	decibel	The amount of increase from the criterion necessary to result in a doubling of the maximum allowable exposure, and the amount of decrease necessary for a halving of the maximum allowable exposure
Average Level	decibel	The level that if it were present continuously, would generate an equal amount of sound energy as the varying levels that are present in the environment.
Time Weighted Average	decibel	A level average with an assumed Average sample period of eight hours
Dose	percentage %	The allowable daily exposure value. A maximum allowable exposure is equal to 100%.

Instrumentation

Sound Level Meter

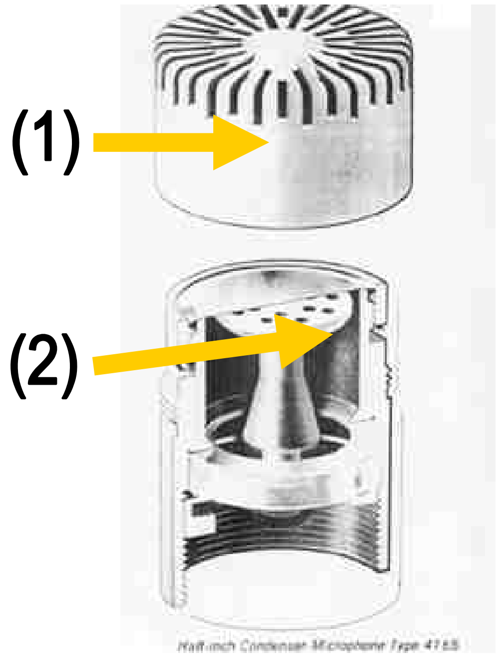


A sound level meter (SLM) is a device which can measure sound and display the measured sound pressure level. This illustration shows a block diagram of major functional components of a basic SLM. As the air pressure levels change in response to the presence of sound waves, the microphone detects the changes and outputs an electrical signal. This signal is conditioned by the remaining components to provide a displayed level appropriate to the measurement application.

Instrumentation

Microphones

Some sound level meters have microphones that can be removed from the meter. These microphones have a protective grid (1) on them that should not be removed by the user. Under the grid is a very thin membrane (2) that moves in response to changes in the sound pressure level. These microphones may be either type 1 or type 2. For most compliance measurements a type 2 microphone is adequate.



Instrumentation

Microphones

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Random

Direct

Pressure

Three different types of microphones are commonly used with sound level meters. Random incidence, direct incidence (free field) and pressure microphone. Random incidence microphones measure sounds almost evenly from any direction, but for best results the microphones should be held in an angle of 70 degrees to the source. Direct incidence microphones measure sound that is directed in a 0 degree angle to the microphone. The microphone should be pointed directly at the source. Pressure microphones in a free field measure sound at a 90 degree angle to the source. It should be held parallel to the source.

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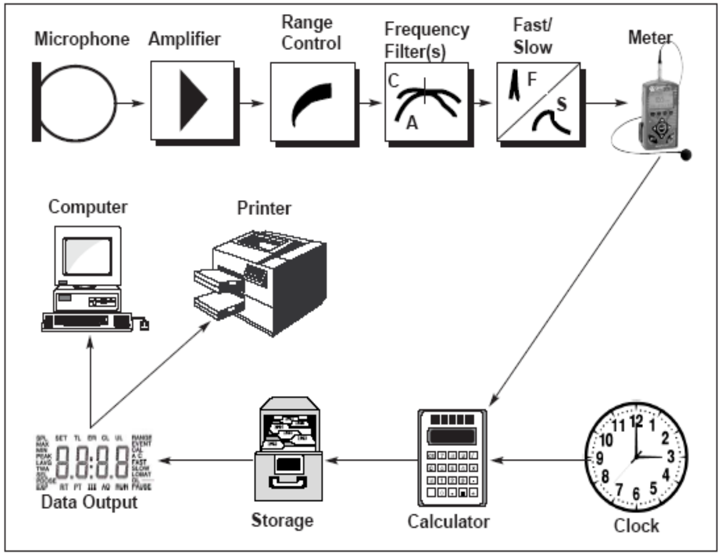
Instrumentation
Noise Dosimeter



A noise dosimeter is essentially a sound level meter which has an internal clock, a calculator, and memory to store measured and calculated data. This a block diagram of a noise dosimeter. The microphone, preamplifier, weighting network, and fast/slow response are the same as for an SLM. The range control is automatic on some meters and must be set manually on others. The clock keeps track of sampling time as well as the time the dosimeter has not been sampling. Some dosimeters may also record how long sound levels exceeded a set upper limit. The calculator computes an L-AV, a dose, TWA, and other data. The memory stores all times, calculations, and measurements

Instrumentation

Dosimeter Microphone

Some dosimeter microphones are designed to be attached directly to the dosimeter chassis (1) with the entire device worn on the shoulder, or they may be designed to be extended on a cable (2) so the chassis may be attached to a belt or put in a pocket while the microphone is attached at the shoulder.

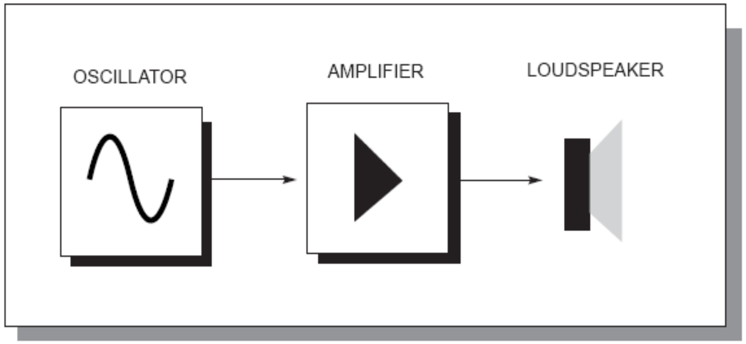
(1)

(2)

Instrumentation

Field Calibration

A calibrator is a device which produces a sound with a fixed frequency at a fixed sound level. The calibrator is connected to a sound level meter or dosimeter to verify the measurement accuracy. Some calibrators may have multi-frequency and intensity capabilities.



Measurement Issues
Typical Approaches

1. Individual Full Exposure Assessment
   This entails full shift monitoring of each individual. It offers the highest level of accuracy. In this approach each worker is monitored for at least one complete work shift.
2. Representative Sampling
   This can be representative from two different view points. You may either monitor a portion of the work shift and expand the results to get the full work shift equivalents, or you may pick one or several workers to monitor and assign their test results to others. In either case this approach can be successfully used, but it is only as good as your assumptions.
3. Area Mapping or Task Based Monitoring
   In these approaches either the measurements are based on the lay out of the facility, or the specific activities of the workers. They can both offer good insights into where noise controls and work practice changes may be applied to reduce the overall exposure to the worker.

Measurement Issues

Typical survey steps

Check Battery: Check the battery condition before AND after doing a survey	
Calibrate: Calibrate the dosimeter before AND CHECK the calibration for drift after the survey. The instrument should not drift more than .5 dB from original calibration level.	
Place Unit: Place the dosimeter on a belt where it is not uncomfortable. You may find that the person to be surveyed does not wear a belt, so have one handy. The unit may also be placed in a pocket if necessary. Use clothing clips to keep the microphone cord close to the body and away from potential snags such as machinery or other equipment.	
Place Microphone: The microphone should be placed on the shoulder with the cord routed out of the way. If the person has a beard make sure it is not going to touch the microphone. If the sound source is directional, place the microphone so it will be on the side closest to the source.	
Work: Make sure the person who is being surveyed is doing the kind of work that is normally done.	
Check It: Throughout the workday you should check the unit. Your presence may prevent tampering with the unit or the microphone.	
Observe: Also observe the person when he/she is unaware of your attention. This will give you additional assurance that your data are valid.	
Remove Unit: Remember to remove the unit before the worker leaves the workplace.	
Record Data: Finally, record all the data as soon as possible to prevent accidental erasure. You also might want to save those records you don't think you'll need. At some time in the future they may become important.	

Measurement Issues

Potential Problems

Microphone Placement: The microphone was not placed correctly. It fell off or it was placed in a position which allowed it to be touched (by a beard, a jacket, or other equipment the person may have worn at the measurement time).
Employee: The person being surveyed tampered with the instrument or the microphone. It is not uncommon for examinees to yell or whistle into the microphone. This is especially critical if the survey is of short duration. During a full day survey this effort must be substantial to significantly affect the result.
Project Assumption: The person worked in a noise environment that was different from the one he/she normally worked in, or in representative samplings, the wrong subject was selected.
Threshold Distortion: The noise level was just below the threshold the majority of the time of sampling. This will cause the TWA/Dose to be low, even though a slightly higher noise level would have resulted in excessive exposure.
Wind: If the wind significantly exceeded 12 m.p.h., the dosimeter may have picked up more sound energy than was actually present. The wind effect on a microphone is the same as if somebody were to blow in your ear.
Battery & Calibration: It cannot be emphasized enough how important it is to check both battery and calibration before and after a survey!

Measurement Issues

External Influences

Temperature: Temperature is normally not a problem in doing noise analysis. The range of operating temperature is available for each instrument on it's specification sheet and in the owners manual. It is, however, important that temperature changes, while doing sampling are limited. Condensation may form on the microphone which will alter the performance. Allow the unit to reach room temperature and stabilize before measuring if the unit has been outside for a prolonged period of time.

Humidity: If you are using an instrument in a moist environment with a relative humidity at or near 100% it is important that you frequently check the metal on the microphone for condensation. If condensation is present, there may also be condensation on the microphone diaphragm which will cause inaccuracies. Reschedule the measurement plan for more favorable conditions.

Measurement Issues Continued
External Influences

Atmospheric Pressure: The dosimeter will work well in any atmospheric pressure; however, the calibrator does perform differently with pressure changes. In the manual for the calibrator you will find a correction factor, normally given as dB correction per 1000 feet of altitude.

Wind: Wind is often the most critical environmental concern. ALWAYS use a wind screen when doing sound measurements. A wind screen will safeguard your unit for winds up to 12 mph.

External Interference: Strong magnetic fields and radio frequency interference can affect readings from any industrial hygiene instrument. In the case of sound measuring instruments, these interferences cause the unit to read artificially high. Every effort is made in instrument design to minimize this potential. If you suspect interference you can perform a simple field test for verification. While in the area where you suspect interference and with the SLM or dosimeter on and measuring sound level, place your calibrator turned off with adapter onto the microphone. You should see the sound level decrease. If it does not decrease, a signal is getting in by some other means than the microphone.

Measurement Issues

What to record in addition to the sound level metrics

1. Dates and Times
2. Model and Serial numbers of the instruments used
3. Pre and Post survey calibration levels
4. Workplace Descriptions
   - Plant location
   - Building number
   - Department number
   - Floor number
5. Task Descriptions
   - Machine type
   - Machine identification
   - Material being used
   - Work rate information
   - Lot size
   - Mobility
   - Variations
6. Environmental Factors
   - Temperature & Humidity
   - Wind
   - RFI
7. Instrument Setting
   - Threshold & Criterion Levels
   - Slow or Fast
   - Weighting
   - Range
   - Exchange rate
8. Unusual Conditions

Standards & Regulations

For Instrumentation

Sound Level Meters, Octave Band Analyzers & Real Time Analyzers

- *ANSI S1.4-1983(R2001) "Specification for Sound Level Meters"*
- *ANSI S1.43-1997(R2002) "Specifications for Integrating Averaging Sound Level Meters*
- *ANSI S1.11-2004 "Specification of Octave Band Filters*
- *IEC 61672–1(2003) – Electroacoustics, Sound level meters, Part 1*
- *IEC 61672-2(2003-04)-Electroacoustics, Sound level meters, Part 2*
- *IEC 61260 – Electroacoustics, Octave band and fractional-octave band filters*

Noise Dosimeters

- *ANSI S1.25 – 1991(R1997) Specification for Personal Noise Dosimeters*
- *IEC 1252 – 1993 Electroacoustics, Specifications for personal sound exposure meters*

Standards & Regulations

Intrinsic Safety

For some applications an instrument rated for intrinsic safety may be required.

- *UL, cUL, Atex, SIMTARS, MSHA – These agencies provide testing laboratories and certification to standards stating where instruments can be used safely.*
- *Zones, Classes, and Divisions – Terminology that users need to understand if their environments may contain hazardous gases or flammable fibers.*
- *IP Ratings – A numeric system that defines how tightly sealed an instrument is. A good indication of water resistance.*
- *Link to our approvals page*

Standards & Regulations

Hearing Conservation & Noise Measurement

- OHSA
- MSHA
- NIOSH
- ACGIH
- DOD
- EU Directive