CHAPTER 39

NOISE DOSIMETERS

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1 INTRODUCTION

Noise-induced hearing loss is one of the most prevalent occupational illnesses in the world, but it is also the most preventable. Noise dosimeters have been used extensively over the past two decades to document noise exposures and ensure compliance with rules and regulations developed by various international organizations and regulatory agencies. In the United States, such dosimeters are required to comply with the American National Standards Institute (ANSI) Specification for Personal Noise Dosimeters S1.25–1991 (R1997), which states that dosimeters should be suitable for measurement of impulsive, intermittent, and continuous noise. Noise dosimeters measure and store sound pressure levels and, by integrating these measurements over time, provide a cumulative noise exposure reading for a given period. Dosimeters can function as personal or area noise monitors. In occupational settings, personal noise dosimeters are often worn on the body of a worker with the microphone mounted on the middle-top of the person's most exposed shoulder.

2 PRINCIPLE OF OPERATION

A dosimeter is a battery-powered, portable instrument, derived directly from sound level meters (SLM) to automate the measurement and calculation of the percentage of the maximum permissible daily noise dose. It consists of a microphone that senses the sound pressure and produces an electrical signal. The output signal is amplified and fed into a frequency-weighting network (most typically, A-frequency weighting). The signal is then squared (sound pressure level is a function of pressure squared) and exponentially averaged with a specified time constant to establish a moving average window in time. The output sound level signal is fed into an integration section (an exponent circuit, threshold circuit, and integrator) that performs the algorithm necessary to compute the percentage criterion exposure (noise dose) according to a particular exchange rate, threshold level, and criterion sound level. The output is indicated as a percentage criterion exposure corresponding to the accumulated data at the completion of the measurement by the indicator circuit. The block diagram for the functional elements of the dosimeter is shown in Fig. 1.

2.1 Noise Dose

Noise dosimeters compute a percentage criterion exposure or noise dose. Noise dose is the quantity that is expressed as a percentage of the maximum permissible daily exposure to noise. Noise dose is

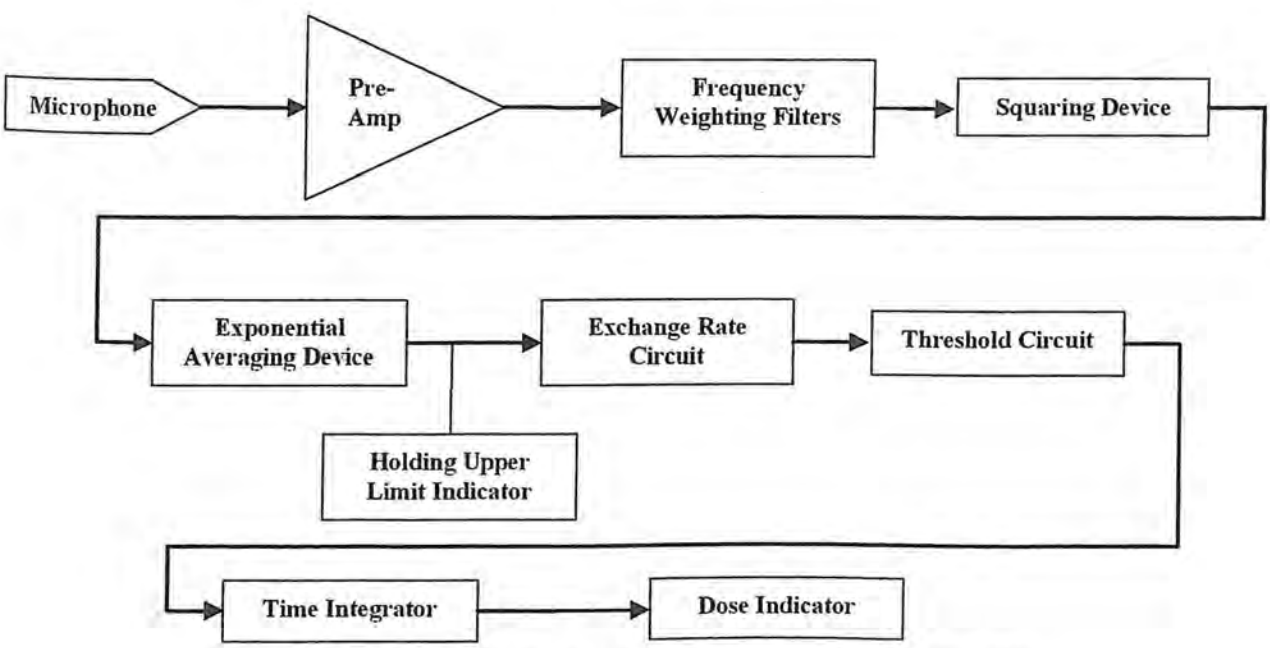

Figure 1 Block diagram of the essential elements of a noise dosimeter.

used in regulations to quantify exposure to noise in the workplace to protect against noise-induced hearing loss. ANSI S1.25 standard defines noise dose by the following mathematical equation:

$$D(Q) = \frac{100}{T_c} \int_0^T 10^{[(L_A(t)-L_c)/q]} dt \qquad (1)$$

where $D(Q)$ = noise dose for exchange rate Q
T_c = criterion sound duration = 8 h
T = measurement duration in hours
t = running time in hours
$L_A(t)$ = slow (or fast) A-weighted sound level in decibels (dB) when the sound level is greater than or equal to a user-selectable threshold sound level, or equals $-\infty$ when the A-weighted sound level is less than the threshold level
L_c = criterion sound level (in dB) specified by the manufacturer
Q = exchange rate (in dB) (can be 3, 4, or 5 dB); and $q = Q/\log(2)$ is parameter that determines the exchange rate

Exposure to a sound level that is equal to the criterion level L_c for a measurement time period equal to the criterion duration T_c yields a noise dose of 100%.

The Occupational Safety and Health Administration (OSHA) guidelines provide an alternate method for computing dose when the work shift noise exposure is composed of two or more discrete time periods of noise at varying levels. The total noise dose in percent is then defined by

$$D = 100\left[\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_i}{T_i} + \cdots + \frac{C_N}{T_N}\right] \qquad (2)$$

where C_i is the total time of exposure at a specified A-weighted sound level, and T_i is the reference duration of noise exposure at that sound level that produces a dose of 100%.

The values for T_i are given in Table G-16a in Appendix A of the OSHA 29CFR 1910.95 regulations. A portion of Table G-16a is shown in Table 1. Table G-16a is derived from the following expression:

$$T_N = \frac{T_C}{2^{(L-Lc)/\mathrm{ER}}}$$

or, for OSHA regulations

$$T_N = \frac{8}{2^{(L-90)/5}} \qquad (3)$$

where L is the *slow* A-weighted sound level. L_c is the criterion or threshold level (90 dB), and ER is the exchange rate (5 dB).

Table 1 Permissible A-weighted Noise Level Exposures

Exposure Level, Slow (dB)	Duration per Day (h)
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
110	1.5
115	0.25 or less

From OSHA Table G-16, 29CFR 1910.95 (A).

2.2 Exchange Rate

Exchange rate is defined in ANSI S1.25 as "the change in sound level corresponding to a doubling or halving of the duration of sound level while a constant percentage of criterion exposure is maintained." Dosimeters may be programmed to accept different exchange rates when performing their computations. OSHA requires the 5-dB exchange rate in its guidelines, while the National Institute for Occupational Safety and Health (NIOSH), the American Conference of Governmental Industrial Hygienists (ACGIH), and most international standards recommend the use of the 3-dB (equal-energy rule) exchange rate.[1,2]

2.3 Criterion Sound Pressure Level

Criterion sound level is the A-weighted sound level that corresponds to the maximum permitted daily exposure (dose of 100%) to noise if continually applied for the criterion time (typically 8 h). Criterion sound level also refers to occupational exposure limits specified by standards and regulations. The current OSHA permissible exposure limit (PEL) or criterion level is an A-weighted sound pressure level 90 dB. ACGIH and most international standards use the 85-dB criterion level, which is also the NIOSH recommended exposure limit (REL).

2.4 Threshold Sound Level

Threshold sound level, in decibels, is the sound level specified by the manufacturer of a noise dosimeter below which the instrument produces no dose accumulation. The current OSHA threshold level is set at 80 dB. The International Electrotechnical Commission (IEC) recommends a 40-dB threshold level.[3]

3 SOUND EXPOSURE MEASUREMENTS

Noise dosimeters are primarily used to measure workers' total noise exposure, especially when the noise levels are varying or intermittent, and the worker moves around frequently during the work shift. Dosimeters are also used to collect data for use in legal proceedings, development of engineering noise controls, and other industrial hygiene purposes.

When planning to conduct noise exposure measurements, steps must be taken to ensure that the dosimeters are calibrated and operated according to manufacturers' specifications. It is also necessary to understand the properties of the acoustical environment, the main measurement objectives as they relate to determining the risk to hearing, and the limitations associated with the use of dosimeters.

3.1 Dosimeter Calibration

Dosimeter manufacturers recommend that the instrument be calibrated with an acoustical calibrator before and after each measurement to verify reliable operation. In addition to field calibration routines, the manufacturers recommend periodic comprehensive calibration and certification of the instrument by an accredited laboratory using traceable reference sources. Field calibration of contemporary dosimeters has been mostly automated through PC-based programs that run the calibration routine, document the time and date, and adjust for any offset in levels.

Figure 2 shows a Larson–Davis Model 706 dosimeter being calibrated at 114 dB sound pressure level (SPL) (1000 Hz) using the Larson–Davis CAL 150 Precision Acoustic Calibrator.

3.2 Operational Settings

Current dosimeters are designed to provide the user with parameters such as noise dose, time-weighted average, sound exposure level, as well as peak, maximum, and minimum sound pressure levels. Most dosimeters also generate statistical and graphical representations of the collected data. ANSI S1.25 specifies that dosimeters should at least provide the following parameters:

Frequency weighting: A or C
Exponential averaging: F (fast); S (slow)
Criterion level: 90, 85, 84, 80, or V (variable)
Criterion duration: hours
Threshold level: 90, 80, or V (variable)
Exchange rate: 5, 4, or 3

3.3 Personal Exposure versus Area Monitoring

A dosimeter may be used as a personal dose meter or as an environmental area monitor. For personal noise monitoring, the instrument may be placed inside a pocket or clipped to a belt. OSHA requires the microphone of the dosimeter be placed in the "hearing zone" of the side of the worker facing the highest noise levels. The hearing zone is defined as hypothetical sphere of 300 mm radius enclosing the head of the wearer.[4] ANSI S12.19, Measurement of Occupational Noise Exposure, standard specifies that the microphone be located on the middle-top of the worker's most exposed shoulder and that it be oriented approximately parallel to the plane of the shoulder, as shown in Fig. 3. However, studies have shown that placing the microphone on the person's body can affect measurements by anywhere from an A-weighted sound pressure level of −1 to +5 dB.[5,6] The amount by which the human body affects measurements depends on the nature of the sound field, the frequency spectrum, the angle of incidence, the absorption of the clothing material, and the position of the microphone on the person. In most industrial settings, the A-weighted sound pressure level

Figure 2 Calibration of a personal noise dosimeter with various components notated and highlighted.

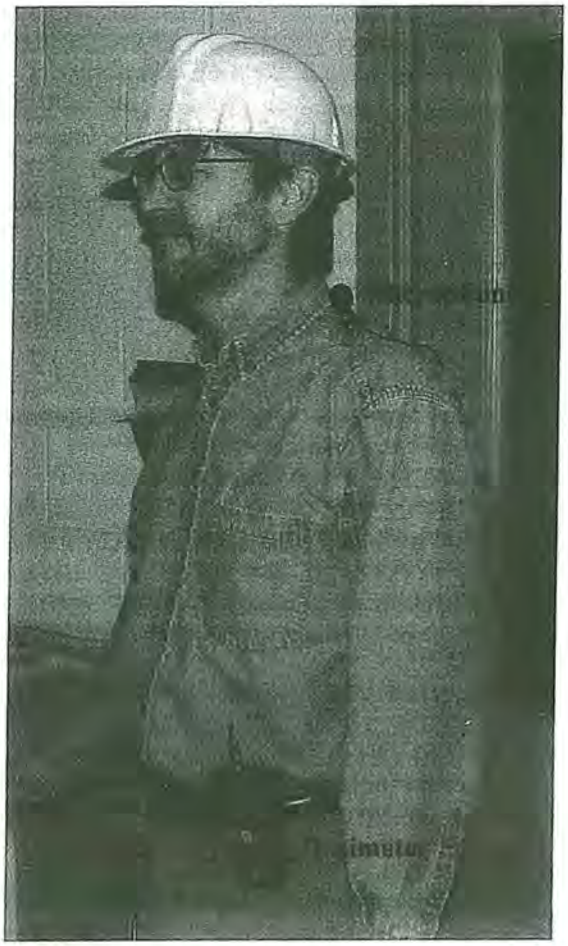

Figure 3 Microphone placement of a noise dosimeter on the shoulder of the wearer.

measurements are typically increased by 0.5 to 1.0 dB when the dosimeter is worn on a person compared with the measurements taken in the undisturbed field.[7]

To alleviate the limitations associated with workers' body distortion, minimize sound survey efforts, and provide better exposure estimates for groups of workers, measurement techniques such as profiling or task-based assessment can been used. The dosimeter's microphone can be mounted on a tripod and placed in the unoccupied worker position. A task-based noise assessment is accomplished by measuring noise varying over time and space for each defined work task.[8] Task-based measurements depend heavily on the accurate identification of the sound field at all points of the task area and the location of the worker versus time.

4 DOSIMETER LIMITATIONS

In addition to the microphone distortions introduced by the worker head and torso, other environmental and electroacoustical factors can limit dosimeter capability and range of operation.

4.1 Mechanical Vibration

Most microphones and dosimeters are sensitive to mechanical vibration, especially at very high SPLs (above 120 dB). Mechanical vibration may cause the microphone or electronics to produce spurious signals in the dosimeter measurement and lead to an increase in the time-weighted average (TWA) and noise dose. To minimize the effects of vibration on the instrument, care must be taken to ensure that the microphone, cable, and dosimeter case are secured or isolated from the source of vibration. Dosimeter manufacturers test and report on the effects of mechanical vibrations by vibrating the entire instrument sinusoidally along the three mutually perpendicular axes at acceleration of 0.98 m/s^2 and within the frequency range of 10 and 500 Hz.

4.2 Impulse Noise

ANSI S1.25 specifies that noise dosimeters should be suitable for measurement of impulsive, intermittent, and continuous noise. OSHA regulations and NIOSH recommendations state that no exposure should be permitted above 140 dB peak sound pressure level. Nevertheless, dosimeters have been used for measurements of noise environments that have levels above 140 dB such as in construction, mining, and law enforcement firing ranges. It must be noted, however, that the OSHA regulations and the ANSI S1.25 standard require that dosimeters operate properly up to 140 dB.

NIOSH studies have found that personal noise dosimeters have inherent limitations and are susceptible to producing erroneous results when they are used in predominantly impulsive noise environments such as firing ranges.[9] These standard dosimeters "clipped" peak noise levels greater than the range of the instrument and acted as if they were at the maximum level of that specified range.

4.3 Measurement Artifacts

Dosimeter microphones are susceptible to inadvertent or intentional tampering by the users. Such tampering may occur by tapping or rubbing the microphone, or by screaming or blowing into the microphone during measurements. Investigations into the potential sound-field contamination of such artifacts showed minimal impact (a fraction of a decibel for thumping and hollering to an A-weighted sound pressure level 1 to 2 dB for blowing with background noises of 85 and 90 dB) on the measured daily TWA when using the OSHA 5-dB exchange rule. However, the use of the International Organization for Standardization (ISO), NIOSH, or ACGIH noise exposure criteria showed much more significant increase (an A-weighted sound pressure level 2 to 5 dB) in the measured TWA.[10] To minimize the effect of such artifacts, most dosimeter microphones are provided with small windscreens that will guard against rubbing and touching, and some isolation against blowing. In addition to the windscreens, contemporary dosimeters are manufactured with built-in keypad locking and programmable automatic timers to reduce the potential for tampering. Finally, close examination of the time-history records can show if any abnormal or unexplained spurious events have occurred during the measurements.

4.4 Wet and Humid Environments

Wet and humid environments present a challenge for collecting personal dosimetry measurements. The dosimeter instrument is typically water resistant and tested to withstand high levels of humidity. However, the microphone's frequency response is usually affected if the relative humidity is high or the temperature of the microphone is close to the dew point. Condensation may occur on the diaphragm of the microphone and can generate intermittent internal noise in the measurement.

When operating a dosimeter in a humid or rainy environment, appropriate all-weather microphones with shields must be selected to prevent water from affecting the diaphragm. Wrapping the microphone or enclosing it using makeshift material should be avoided because it can lead to serious errors in the measurements.

Dosimeter manufacturers test for variations of SPLs over some specified relative humidity range.

4.5 Temperature

Current dosimeters are required to operate properly within ordinary indoor temperature ranges. Permanent damage can occur when they are operated or stored at extreme temperatures. The manufacturers are required to state temperature ranges over which the dosimeter, including the microphone, will meet national and international standards. Typically, dosimeters can be operated safely between -15 and 50°C and can be stored (with the battery removed) at temperatures between -20 and 60°C.

4.6 Electromagnetic Interference

Current dosimeters are required to comply with national and international electromagnetic compatibility standards. Manufacturers test the performance of dosimeters to electromagnetic interference at powerline (50 or 60 Hz) frequencies. However, these standard dosimeters might be susceptible to electromagnetic and radio-frequency interference when operated near sources that generate strong electric and magnetic fields such as arc welders and furnaces, cellular and communications equipment, or induction heaters. ANSI S1.14–1998 (R2003) (Recommendations for Specifying and Testing the Susceptibility of Acoustical Instruments to Radiated Radio-Frequency Electromagnetic Fields, 25 MHz to 1 GHz) provides specification and testing for susceptibility radio-frequency and electromagnetic fields.[11] To check for electromagnetic interference, the microphone might be replaced with a shielded capacitor (or "dummy microphone") with similar impedance. If electromagnetic interference is observed in the dosimeter reading, then action must be taken to shield the instrument.

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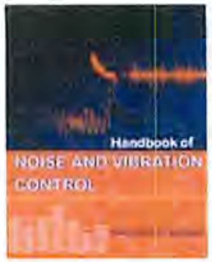

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