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NATIONAL SAFETY COUNCIL
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STATE OF THE ART FOR NOISE ABATEMENT

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In 1969, the United States Department of Labor issued what it characterized as guidelines for the noise standard. This document, known as Bulletin 334, spells out exactly what steps an employer must take in order to be in compliance with the standard. After the present OSHA noise standard became effective, the Department of Labor reissued Bulletin 334 and indicated that this document applied to OSHA noise standards.

General Motors has taken the position that a plant is in compliance with the OSHA noise standard if it has instituted a program based on the eight points listed on page 15 of Bulletin 334. The purpose of this discussion is to show how GM has established a noise program based on Bulletin 334 and to present examples of engineering solutions that General Motors has used to reduce plant noise levels.

This should not be interpreted to mean that we have found an engineering solution for each and every noise problem in our plants. It is not realistic to expect immediate reduction of noise to the level where hearing protectors are not required. We note that OSHA Bulletin 334 recognizes this, and I will quote from that bulletin the eight points in a total noise program:

1. A detailed survey of sound levels and sound spectra to determine the sources of excessive sound levels.
2. Initiation of engineering studies to determine methods for reducing sound levels at their sources.
3. Planning and initiation of feasible administrative controls, such as modifying production schedules to divide noisy jobs among enough people to bring each below the permissible limit or spreading part-time noisy operations.
4. Initial audiograms for personnel excessively exposed.
5. Installation of a personal protective equipment program.
6. Follow-up audiograms at appropriate intervals to assess effectiveness of

the personal protective equipment program and administrative controls.

7. Installation of engineering controls or process changes to reduce noises at their source.

8. Repeated noise surveys to measure effectiveness of the engineering changes. When the compliance plan involves long-term engineering projects (for example, one or two years), it may be revised from time to time as conditions change. The orderly completion, on schedule, of the various phases of the compliance plan, together with other components of the hearing conservation program, will be considered compliance with the regulation.

Engineering Controls

One of the first steps taken to control plant noise in General Motors was the development of the General Motors Corporation Sound Level Specification for Machinery and Equipment. There are five key items in the specification:

1. The request for quote shall include the cost required to meet this sound specification, stated as an alternate and separate item to the cost of the vendor's standard product.
2. The purchaser shall have the option to verify sound levels at the vendor's plant prior to shipment.
3. Sound levels shall be measured during the simultaneous operation of all components and accessories when running under all anticipated operating conditions. This means that measurements are to be made under actual loaded conditions with parts or materials provided by the purchaser.
4. Steady state or cyclical sound levels at the operator's position and at all other points three feet from the equipment shall not exceed 80 dBA.
5. Recognized industry standards are used for the measurement of fans, compressors, motors, and pneumatic tools.

While the purchase specification is a

NOISE INSTRUMENTATION, EQUIPMENT, AND PROTECTION DEVICES

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subjected to sound exceeding those listed in Table G-16, feasible administrative or engineering controls shall be utilized."

Here is a brief review of what the government considers to be administrative controls: (1) arrange employee's work schedule and/or work station to limit his noise exposure; (2) add additional people and rotate employees; (3) perform high noise level operations at night.

Administrative noise controls must receive serious consideration—they are part of the standard. They also provide a practical means of taking care of many troublesome noise problems.

Peragonal Protective Equipment

General Motors recognizes the need for an overall program to reduce plant noise levels to protect employees. It will be many years, however, before all noise problems could be solved by engineering means, assuming that feasible solutions will be developed. In the meantime, personal hearing protectors must be used to protect employee hearing. Hearing protectors will, in some cases, provide more protection for the employee than an engineering solution.

Hearings on the occupational noise exposure standard 1910.95 proposed by the Occupational Safety and Health Administration have recently been concluded in Washington. While General Motors recognizes the desirability of an overall program to reduce plant noise levels and to protect the employee, General Motors contends that employers should be given the option of using either engineering or administrative controls or personal protective equipment as a means for protecting employees from harmful noise exposures.

Summary

This paper has discussed specific examples of noise abatement techniques which GM has applied. General conclusions cannot be drawn from the specific cases cited. The abatement techniques and the relative success or failure of the techniques should only serve to keep us aware of the possible solutions. Each case must be considered on its own merit.

useful and necessary tool for noise control, it has limitations and certainly will not solve all noise control problems. Since the recent noise hearings began in Washington, D.C., we are often asked why GM argues the difficulty and expense of engineering noise out of our plants when we have four years' experience using an 80 dBA purchase specification. Here are three reasons why we are using an 80 dBA purchase specification to achieve compliance with present standards:

1. We have had considerable success with the purchase specification; however, our suppliers have not been able to build all of our new equipment within limitations. In many cases, we must continue to purchase such equipment if we are to produce automobiles.

2. GM is responsible for the noise exposure of the employee. In typical factory situations, this exposure is due to many sources, and it is necessary to limit each source so that the additive effect of noise does not allow the employee to be exposed above the allowable limit. For example, in theory, it is possible for ten 80 dBA sources to cause a 90 dBA noise level.

3. Much of our existing equipment will be in use for many years and will not be immediately replaced with new equipment which meets our noise specifications. The close proximity of machinery and the fact that technology has not been developed to solve all noise problems are factors which must be considered.

Retro-Fit

The specification for the purchase of new equipment is an important part of our total program, but there are thousands of machines now in use which will continue to be used for many years. Therefore, it may be necessary to retro-fit noise reduction into existing equipment if such action would amount to a feasible solution.

Administrative Controls

The use of administrative controls is a necessary step in a complete noise control program. The standard leaves no doubt of our responsibility to use these measures to protect people's hearing. The OSHA standard states: "When employees are

I would like to begin my discussion of instrumentation by briefly discussing microphones, a very important part of any sound analysis system.

Virtually all sound measuring instruments require microphones to convert sound waves into electrical signals which the instrument can interpret and analyze. In practice, there are three different types of microphones commonly used today in conjunction with sound measuring instruments. These are Piezo-Electric, Condenser, and Electret microphones.

The piezo-electric microphone (abbreviated PZT and sometimes called a ceramic or quartz crystal microphone) is a rugged microphone which is relatively unaffected by high temperature or humidity. The frequency response of a typical PZT microphone is flat from 20 to 8000 Hz. Unlike the other two types, these microphones do not require preamplifiers, but for this reason, a correction factor must be included in measurements if the microphone is placed at the end of an extension cable. The primary advantages of these microphones are low cost and resistance to damage under adverse operating conditions. A typical PZT microphone may be purchased for \$35.

Electret microphones which are suitable for use in industrial environments have only recently become available. The manufacturer of electret microphones reports that they are unaffected by high temperature and humidity, and that frequency response is flat from five to 20,000 Hz. The cost of an electret microphone is roughly \$250, considerably more than a typical ceramic microphone, but frequency response is significantly better.

Condenser microphones have the best frequency response of all microphones in current use. They are available in models which are essentially flat in response from 20 to 40,000 Hz. The dynamic range of these microphones is typically 40 to

145 dB, although models are available which will measure sound pressure levels beyond this range. They may be used at temperatures up to 125°F. and are unaffected by high humidity unless water condenses on the microphone. The cost of a condenser microphone with these characteristics is about \$350. This is higher than a comparable electret microphone, but the frequency response is better.

Both electret and condenser microphones must be used with preamplifiers. For this reason, no correction is required when these microphones are used with long extension cables.

Because sound waves coming straight at a microphone can "pile up" on the diaphragm of the microphone and cause erroneous readings, microphones have been designed which will correct for this effect. These "free field" microphones, as they are called, should be pointed directly at the sound source being measured in order to obtain an accurate reading.

"Random incidence" microphones are not corrected for this effect and may give erroneous measurements if pointed directly at a source of noise being measured. They are intended primarily for use in areas where sounds of approximately the same levels are approaching from all directions.

Ceramic, electret, and condenser microphones are available in either free field or random incidence types. It is important to choose the right microphone for the right application. It is of equal importance to use the microphone you have in the proper fashion in order to obtain accurate measurements.

When purchasing a sound level meter or dosimeter, a particular microphone is generally supplied with the instrument. The quality of the microphone will most often determine, or at least be indicative of, the overall accuracy of the instrument. It is therefore wise to find out what

type and quality of microphone is being supplied with any sound-measuring instrument.

Certainly, the most basic and widely used instrument designed to measure sound level is the sound level meter. Like most sound-measuring instruments, the sound level meter utilizes a microphone to convert a sound wave into an electrical signal. The sound level meter analyzes this signal and displays the sound level as a decibel reading on a meter scale. While all sound level meters operate on this basic principle, they vary greatly in accuracy, capabilities, and cost.

With regard to accuracy, sound level meters are generally categorized into three types. These categories, called Types I, II, and III, are set forth in the ANSI "Specifications for Sound Level Meters," Document S14-1971. In general terms, a Type I sound level meter can be considered accurate to within one decibel, a Type II sound level meter within two or three decibels, and a Type III sound level meter within four or five decibels. For general surveying of industrial workplaces, most safety directors and industrial hygienists choose Type II sound level meters. When analyzing a particular noise problem in depth, however, a Type I sound level meter is more desirable.

The capabilities of sound level meters vary greatly from one model to another. Some are designed to perform one or two specific functions, while others are capable of serving many purposes. Some models, for example, are intended primarily for use in determining OSHA compliance. They will only make A-weighted sound level measurements with slow or fast response. Such a meter may suffice for some applications, but many other features are available.

Only a few sound level meters have the capability to accurately measure impulse or impact noises. These are sounds of duration of less than one-half second which recur at intervals greater than one-half second. OSHA presently requires that no impact noise levels exceed 140 dB, and they are proposing to limit the number of impact noises which may be heard at this level and even lower levels. The capability of your sound level meter to measure impact noises may be essential if your company uses shears, punch presses,

or other equipment which generates high impact noise levels.

There are three additional weighting networks available on some sound level meters besides the "A" weighting which is most commonly used. While these filters, called the "B," "C," and "D" networks, have limited applications, some present or future standards may require their use.

Some sound level meters also permit linear measurements to be made (i.e., measurements without any weighting network in the circuits of the sound level meter). The linear capability and weighting networks can sometimes be used to establish the high or low frequency content of a sound. For example, if a C-weighted measurement of a sound is significantly higher than an A-weighted measurement of the same sound, one can be fairly certain that the sound has a large low frequency component, since A-weighting attenuates much more at low frequencies than does C-weighting.

A much easier way to define the spectral composition of a sound is to use an octave or one-third octave filter set available with some sound level meters. When a signal is passed through such a filter set, all frequencies are filtered out except those falling into a particular chosen range. In a typical octave filter set, there will be eight to ten ranges to choose from. In the case of a one-third octave filter set, there will be 25 to 35 ranges to choose from. Those frequencies which contribute most to the overall level of a particular sound can be singled out using a filter set. Such information is often very useful in determining the exact source of a noise and a solution to the problem.

Input and output jacks are also available on some sound level meters. This allows the circuitry in the meter to be used to amplify, attenuate, or filter a signal before it is passed to a tape recorder, analyzer, or some other instrument.

As would be expected, the cost of a sound level meter is proportional to its accuracy and the number of features it has to offer. A Type II meter which will permit A-weighted measurements to be made can be purchased for about \$350. A Type I meter with some of the features described above will cost in excess of

\$1700. A variety of features are available on sound level meters which are priced somewhere between these two extremes. It is important that the possible uses of a sound level meter be determined before a final decision is made as to which model will be purchased.

Next to the sound level meter, the most commonly used instrument for determining employee noise exposure in the workplace is the dosimeter. The dosimeter is a small instrument which can be hung on a belt or slipped in the pocket of a worker, with a remote microphone clipped to his shirt collar near one ear. The microphone picks up the same sounds the worker hears and keeps track of how long each sound level is heard throughout the day. At the end of the day, the employee's daily noise dose may be read directly off the unit or, as is the case with one particular model, a memory cell is removed from the dosimeter and placed in a separate device to obtain a readout of the exposure.

There has been a great deal of controversy of late over the value of dosimeters, due to alleged inaccuracies in their measurements. In laboratory tests, inaccurate readings are often obtained, and conditions in the workplace can add to these errors.

Employee cooperation (or lack thereof) is one common problem. Some employees will intentionally make more or less noise than usual while wearing a dosimeter, or even remove the dosimeter when no one is around to monitor him. Such actions can cause erroneous data to be collected, but it is usually recognizable as such.

Dosimeters and/or their microphones may also be damaged when left in the hands (or more likely the pocket) of a worker who may have little regard for the instrument. We at Case Company are regularly returning dosimeters to the manufacturers for repair and recalibration. The solution to such problems, of course, is employee education.

While it may be true that some dosimeter-measured exposures could be in error by as much as 35 per cent, I am not sure that many persons could do better armed with a sound level meter and a stopwatch, which is the only practical alternative. One distinct advantage to dosimeters is

that one person can monitor 15 or 20 persons per day, if finances permit purchasing that many units. One person using a sound level meter could match that rate only rarely under ideal circumstances.

Several manufacturers have dosimeters available for about \$500. If a readout device is required, it will cost about \$250 more, but one readout unit may be used with any number of dosimeters. One dosimeter which has recently been introduced may be calibrated by the user and is switchable between an 85 dBA/16-hour criteria and a 90 dBA/8-hour criteria. Cost is about \$800. Most other models must be returned to the manufacturer for calibration, and would become obsolete or have to be returned to the manufacturer for modification if OSHA changes to an 85 dBA/16-hour criteria as proposed.

Because changes in battery voltage, temperature, and other factors can affect the calibration of any sound-measuring instrument, it must be checked as often as possible with an accurate acoustical calibrator. Generally, these devices are battery operated and may be taken along with the sound level meter so calibration can be checked immediately before and after measurements are taken. Most of these portable models generate just one or two sound levels at a particular frequency. A few will allow a choice of sound levels and/or frequencies at which calibration can be checked.

Several models which are accurate to within ± 0.5 dB are available. The "Pis-tonphone" is a unique calibrator, unaffected by small changes in voltage supplied. It is accurate to within ± 0.2 dB, but costs \$475. Also available is a table model which operates on 110 volts A.C. It will calibrate at any of eight sound pressure levels between 85 and 117 dB, accurate to within ± 0.5 dB. It is available with a built-in timing mechanism which will automatically shut off the signal after a set period of time, for easy calibration of dosimeters. This unit costs \$325.

It is important to remember that while a sound level meter can be calibrated at almost any sound pressure level, a dosimeter will have an effective range between 85 or 90 and 115 dB. A calibrator intended for use in calibrating both sound

level meters and dosimeters should, therefore, calibrate at some sound pressure level between 90 and 115 dB.

Microphones, acoustical calibrators, dosimeters, and sound level meters are the primary pieces of equipment plant safety personnel are likely to require for checking plant noise levels and employee noise exposure. Other available instrumentation for sound and vibration analysis are too numerous to discuss in depth in this paper. There are a few, however, which should be mentioned in any discussion of sound measuring equipment.

A tape recorder is often useful for obtaining a permanent record of a particular noise problem. The same recording can be analyzed many different ways by equipment which could not be taken to the source of noise. Tape recorders with many desirable features are available in a variety of sizes and price ranges. A tape recorder is a real asset when analyzing sounds of very short duration, or when it would be impractical to take larger, more delicate instruments to the source of the sound.

A heterodyne analyzer system with a graphic level recorder will permit octave, one-third octave, and narrow band analysis of a continuous signal and give a printed graph of the frequency distribution for a permanent record. Its capabilities far exceed those available with any sound level meter. One drawback with this system is that the sound must be of duration of at least ten seconds (more, in most instances) to give the system ample time to perform its analysis and print the result. This problem can be overcome with a real time analyzer, which will display the frequency distribution of a sound at the same time the microphone picks up the sound. Thus, sounds of very short duration can be analyzed with a real time analysis system.

In recent years, computer systems have been introduced which will perform real time analysis and much more. Such systems can be used to do fast Fourier analysis, something no ordinary analyzer could do. Data and programs may be stored on paper tape or magnetic discs; output may be displayed on a teletype, cathode ray tube, or an X-Y plotter. The capabilities of such systems are practically unlimited.

I would now like to turn briefly to equipment necessary for performing audiometric examinations (hearing tests). OSHA is proposing a new occupational noise exposure regulation which would require annual audiometric tests of all employees whose noise exposure exceeds the limits set in the regulation. Many companies, I'm sure, will choose to do such testing in-house and will, therefore, soon be making plans to purchase audiometric test equipment.

The basic instrument required to take an audiogram is the audiometer. There are basically two types of audiometers: manual and self-recording. As the names would imply, manual audiometers require a technician's constant attention to operate the unit and record the test results; a self-recording audiometer requires only the push of a button to initiate a complete hearing test, including a chart of the results.

Either type of audiometer produces a tone in a set of earphones at each of six to ten test frequencies. Each ear is tested separately. In most modern audiometers, the tone may be chosen as continuous or pulsed. (The pulsed tone is generally easier to discern, especially by persons with tinnitus.)

In the case of a manual audiometer, the sound level of the tone is raised manually by the person administering the test from a zero decibel level until the subject wearing the earphones signals (usually by the raise of a hand) that the tone has been heard. The person administering the test then makes a mark at the proper location on an audiogram card and moves to the next test frequency. To assure that the audiogram is valid, the test should be administered at least twice at each test frequency. The quality of the test and the validity of the audiogram are for the most part determined by the ability of the person administering the test. Not much can be told about the quality of these audiometric examinations by looking at the resulting audiogram cards.

An automatic audiometer tests at each frequency for about 30 seconds. The subject responds to the test by pressing and holding a pushswitch button while he hears the pure tone signal, and releasing the button when he no longer hears the tone. While the button is released, the test

tone automatically increases in level until the subject again hears the tone and presses the button. Every response the subject makes during the examination is automatically recorded. One can establish the validity of the audiogram while the examination is being administered, immediately thereafter, or at any later date. By checking the audiogram cards, it is not too difficult to tell which audiometric examinations were properly administered by the technician and instructions understood by the subject.

It is of utmost importance that the person receiving an audiometric test be in a perfectly quiet, vibration free environment. ANSI Standard S3.1-1960, Criteria for Background Noise in Audiometer Rooms, specifies the maximum permissible background noise levels in audiometric testing rooms. One of the easiest ways to attain such levels is to purchase a pre-fabricated audiometer booth. These booths are available in many sizes and designs so they can be placed in almost any convenient location. This includes putting booths inside mobile vans so the same audiometric testing facilities may be used at a variety of locations. With self-recording audiometers, as many as six or eight persons can be tested simultaneously in these mobile audiometric testing centers. These vans may also be used for discussing with employees the importance of hearing conservation, instructing in the proper use of ear protection, and fitting ear protection.

There are basically three types of ear plugs commercially available: pre-molded, custom-molded, and wear-molded. Pre-molded plugs are generally made of some type of soft plastic material molded in a shape which will fit in and seal the ear canal. This type of plug is easy to insert, washable with soap and water, and reusable for a year or more. Sizes and shapes are available to fit most ears comfortably. Pre-molded plugs are available for seventy-five cents to a dollar per pair.

Custom-molded plugs are also made of soft plastic or rubber. Each plug is custom made to fit one person's ear. They are washable and reusable, but are more expensive, about five dollars per pair.

Wear-molded plugs are generally made of wax, fibres, foam, or a combina-

tion of these. To insert, the wearer rolls the plug material into a small cylinder which is placed in the ear canal. These types of plugs can be very comfortable and afford good protection, depending on the care taken to properly insert them. Disposable plugs cost about ten cents per pair.

Besides the attenuation characteristic, which is an important consideration in choosing any type of ear protection, there are other factors which should be considered when comparing different styles of plugs. Ear plugs must be comfortable enough that the worker will be able to wear them all day. This requires the design of the plug be such that it will fit most ear canals, and ideally, the plug should be available in more than one size. At the same time, the plug must fit tight enough to give a good seal, and not fall out of the ear. Finally, the plug must be hygienic—either washable or disposable.

Ear muffs cover the entire ear instead of just the ear canal. Because there is no special technique involved in fitting muffs, a good seal of the ear is generally obtained with their use. They may not give as good a fit if worn over a hard hat, safety glasses, or other head wear. Ear muffs are washable, and the cushions which fit around the ears are usually replaceable (at minimal expense). Ear muffs will last indefinitely and are not as easily lost as plugs. It is easier to spot a pair of muffs on a worker than it is to see if he has plugs in his ears.

Ear muffs must also fit comfortably and seal well around the ear to be effective. This means the head band must extend and the muffs must swivel on the head band to accommodate all head sizes and shapes. The head band should also be of such a design that it rests comfortably on top of the head. Finally, the muffs must apply sufficient pressure around the ear to ensure a good seal, but not so much pressure as to cause discomfort.

No one type or style of ear protection will afford satisfactory attenuation of noise, or prove comfortable enough for all day use on all individuals. It is a good idea, then, to offer employees both plugs and muffs and, when possible, offer a choice of each.

The cost of a particular type of ear protection will not generally be a signifi-

cant factor in deciding what type to purchase. Molded plugs costing seventy-five cents to a dollar a pair will survive a year or more of daily use. Good muffs that will last indefinitely with a little care and maintenance are available for seven to ten dollars. Even disposable plugs at about ten cents per pair should cost no more than \$25 per worker per year. These costs are certainly insignificant when compared to the high cost of implementing engineering controls.

If properly fitted, both plugs and muffs will afford about the same attenuation of noise. This attenuation will generally be

15 to 25 decibels in the low frequencies and 20 to 40 decibels in the higher frequencies. Attenuation characteristics of a particular pair of ear protectors as tested in accordance with ANSI S3.19-1974 should be available from the manufacturer, and this data should certainly be evaluated when comparing ear protection.

For additional information and an unbiased evaluation of comfort and attenuation of most commercially available plugs, see document FAA-AM-73-20, "Ear Protector Ratings," prepared for the Department of Transportation by the FAA Civil Aeromedical Institute.

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