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NOISE AND ITS MEASUREMENT

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MORALISTS may debate whether the world is better for the many technological advances of the past century, but no one can deny it is noisier. When man flies a jetliner, builds a skyscraper, or operates a factory, he makes noise—a lot of it. It seems that you can't do big things without making big noises.

But man the noisemaker is also man the noisechaser, spending many millions of dollars each year to reduce noise. The direct cost of devices, materials, and labor is large, but only part of the story; add the cost of efficiency sacrificed in automobile and jet engine noise mufflers, and you have an annual price tag well over $100-million. Of this amount, the relatively small part spent on noise-measuring equipment must be considered a bargain, for measurement is the only way of telling whether the rest of the money is wisely spent.

Man—The Noise-Measuring System

Man is really the ultimate noise-measuring system and the science of noise measurement is often an attempt to measure noise the way the human mechanism does. Of primary interest is the concept of loudness. Loudness is a purely subjective parameter, beyond direct physical measurement. But it is related to the pressure level of the sound (sound being a variation in normal atmospheric pressure), and this relation provides the starting point of noise measurement.

Sound Pressure Level & the Decibel

Since the term "decibel' is often abused, we will first state what it is *not*. It is not a specific quantity, like a ton, or a mile, or a minute. It is really the logarithm of a ratio of one quantity to a reference quantity. In noise measurement, the reference quantity is a pressure of 0.0002 microbar (dynes/sq. cm.), which is about the pressure of the weakest sound that can be heard by a person with very good hearing in a very quiet place. One microbar pressure equals approximately one-millionth of normal atmospheric pressure. The range of pressures detectable by the human ear is so great that it is easier to use decibels than microbars to express sound pressure level. The relation is: *sound pressure level (db)* $= 20 \log (P/0.0002)$ where P is the root-mean-square sound pressure in microbars, for the sound in question.

When you use the term *decibel*, then, you should keep in mind the reference level you are using in the implied comparison. The level is often stated as, for instance, *db re 0.0002* μ*bar*.

Most everyday sounds lie in the range from 50 to 90 db. It's doubtful that you've ever heard a noise louder than 140 db. Fig. 3 shows where some common noises lie on the db scale.

One last word about the decibel: You'll note from the above equation that it's logarithmic, and you must consider this when combining decibels. Two 60-db noises combine to produce a 63 (not 120) db noise.

Frequency

The ear's sensitivity varies with frequency, and the response curve itself varies with sound pressure level. If we are to relate sound pressure level to the subjective concept *loudness*, we must compensate for the ear's frequency response. This response is shown in Fig. 1, where all points on any single curve represent equal sound pressure level. These curves are based on equal-loudness contours determined by Robinson and Dadson at the National Physical Laboratory, Teddington, England. Note the peak response at about 4000 cycles and the substantial roll-off below a few hundred cycles. We can see from this chart that a sound of 80-db sound pressure level sounds 90 phons "loud" at 4000 cycles but only 60 phons "loud" at 45 cycles. (A phon is a unit of loudness level. By definition, the number of phons equals the number of db of an equally loud 1000-cycle tone.)

The information shown in Fig. 1 is based on many experiments using a pure-tone source. Since most noises are not pure tones, some experts prefer response data based on random-noise experiments. But all agree that some compensation for the loudness-*vs*-frequency effect must be incorporated in any realistic noise measurement that is used.

Microphones for Noise Measurement

Noise measurement always begins at a microphone, the place where sound is converted to voltage. If the voltage output doesn't correspond to the sound input, the measurement will not give correct results. For this reason, proper choice of microphone is all-important.

Three types of microphones are used in noise measurement: piezoelectric, capacitor, and dynamic. Of these, the first two are most widely used in sound-level measurements.

The most popular microphone for sound measurement has long been the Rochelle-salt piezoelectric type, favored for its high output and good frequency response. Its major drawback, known by anyone who ever left one in a closed car on a hot summer day, is its sensitivity to temperature and humidity.

A fairly recent development is the PZT (for lead titanate-lead zirconate) piezoelectric microphone. The PZT offers out-

Man, the noisemaker, spends millions each year to reduce noise. In order to check on the effectiveness of his remedies, instruments must be used to measure noise level. Here is how these instruments do their job.

A sound-level meter being used to check the noise level inside an airliner.

put and frequency response comparable to those of the Rochelle-salt microphone, without the troublesome temperature characteristics. The PZT microphone is gaining fast acceptance for its electrical excellence and reasonable cost.

The capacitor microphone takes the prize for frequency response and also (wouldn't you know) for highest price. It requires a source of polarizing voltage and a preamplifier right at the microphone itself. For most measurements, the difference in frequency response between the measurement-type PZT and capacitor microphones would not justify the considerable difference in cost. Still, if you need optimum frequency response above 8 or 10 kc., the capacitor microphone may be worth the difference.

When a piezoelectric or capacitor microphone is used at the end of an extension cable (as is often desirable), correction factors must be applied for cable length. The dynamic microphone does not require these corrections and is, therefore, often used in such applications.

Sound-Level Meters

The basic noise-measuring instrument is the sound-level meter, an example of which is shown above. It includes a microphone to pick up the sound being measured, a calibrated attenuator, weighting networks, an amplifier, and an indicating meter. The weighting networks, based on frequency-response data similar to that shown in Fig. 1, represent an attempt to convert raw sound pressure into something more representative of the way we hear things. Specifications for weighting networks are standardized in the ASA "American Standard for Sound-Level Meters for the Measurement of Noise and Other Sounds" (S1.4,1961). See Fig. 2.

Sound-level meters come in a variety of shapes and sizes. Perhaps the simplest is a sound-survey meter. Strictly speaking, this is not a sound-level meter (*i.e.*, it doesn't completely conform to the ASA specification mentioned above), but it does measure sound-pressure level and does include weighting networks. This instrument is small, inexpensive, and easy to use and is very popular with the many people who want merely to measure, say, relative loudness of two similar sounds, or who want to make "before" and "after" noise checks in the process of noise-proofing a machine, office, etc. Because of its small size and battery operation, it is an excellent device for making spot checks of noise almost anywhere.

The true sound-level meter is a "must" for anyone who is undertaking serious noise measurements. A good sound-level meter boasts a sensitive, nondirectional microphone, a precise attenuator, a built-in calibrator, a choice of fast or slow meter response, provision for using other input transducers (such as a vibration pickup or a special-purpose microphone), and an auxiliary output connector, so that the output can be fed to an analyzer or recorder. If the sound-level meter is to be used in the field, it should contain its own power supply and be lightweight and easy to carry.

The $400 or $500 paid for a good sound-level meter is an important investment in any anti-noise campaign.

Analyzers

Knowledge of the frequency spectrum of a noise is often very valuable, especially when you are trying to track down a specific noise component. The sound-level meter, even with its weighting networks, reveals very little about frequency distribution. By feeding the output of the sound-level meter to an analyzer, however, you can "tune in" the noise in just about any part of the audio spectrum.

Sound analyzers may be classified by bandwidth, or selectivity, characteristics. The most common types have bandwidths that are a constant frequency or a constant percentage of frequency. A typical constant-frequency-bandwidth analyzer has a response with a four-cycle flat top and very high rejection outside the passband. The most common constant-percentage-bandwidth analyzer is the octave-band analyzer, which contains a set of bandpass filters, covering ASA-specified octave frequency bands. Other analyzers use half-octave, third-octave, and even narrower bandwidths. With some instruments, you can switch to any one of two or more characteris-

Fig. 1. Loudness for constant sound-pressure levels (SPL).

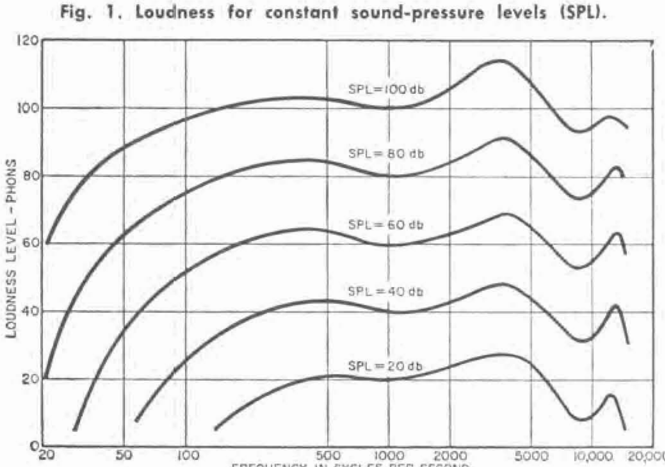
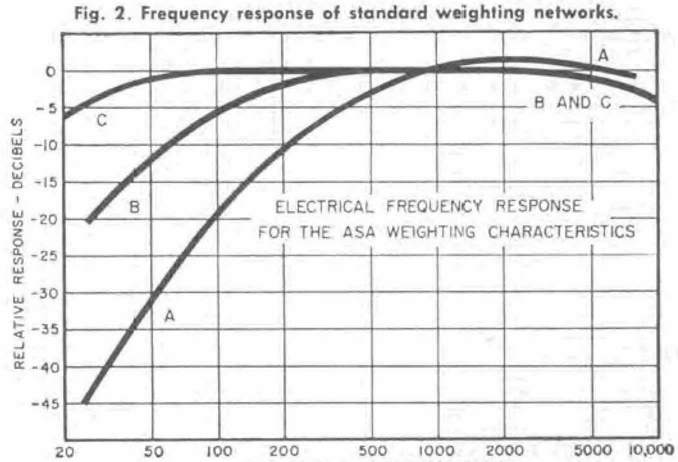


Fig. 2. Frequency response of standard weighting networks.



tics, depending on the application.

The narrower the bandwidth, the more information can be gained from the analysis. Therefore, the narrow-band analyzer reveals much more about the noise than does the octave-band analyzer. But for most noise studies, the octave-band analyzer is entirely adequate, and bringing in a narrow-band analyzer would be like bringing a telescope to a football game.

Impact-type noises require special handling and a special instrument, the impact-noise analyzer, is the only convenient way of measuring significant properties, such as peak level and duration.

Recorders

Level recorders are widely used to chart data from sound-level meters and analyzers. The use of the recorder greatly increases the usefulness of noise-measuring equipment. For instance, a sound-level meter set up to monitor traffic noise at a certain spot can be left unattended while a recorder charts noise level *vs* time. By driving a recorder from a sound analyzer (in turn driven from a sound-level meter), you can plot the curve of amplitude *vs* frequency of noise. And, of course, in almost any type of measurement, it's nice to have a record on paper.

Another type of recorder—the tape recorder—can be used to preserve a noise for later playback for laboratory analysis. For this type of work, a high-quality magnetic tape recorder must be used.

Other accessories found in the well-equipped noise laboratory are calibrators, both electrical and acoustical, to insure accurate measurements, special-purpose microphones (for very high noise levels, for instance), tripod, extension cables, oscilloscope, and vibration-measuring apparatus.

Measurement of Noise

Sometimes noise measurement simply means having a sound-survey meter tell you that the noise is so many db. Sometimes it involves much more. It all depends on the nature of the problem and how much it's worth to solve it. Whatever the measurement, you will be using a sound-level meter either to indicate noise level or to feed an analyzer for further interpretation.

A sound-level meter is deceptively easy to use. You turn it on, check its calibration, place its microphone at the desired point of measurement, switch to one of the weighting networks (*A*, *B*, or *C*), and turn an attenuator switch until the meter gives an on-scale indication. The sound level is indicated by the sum of the meter reading and the

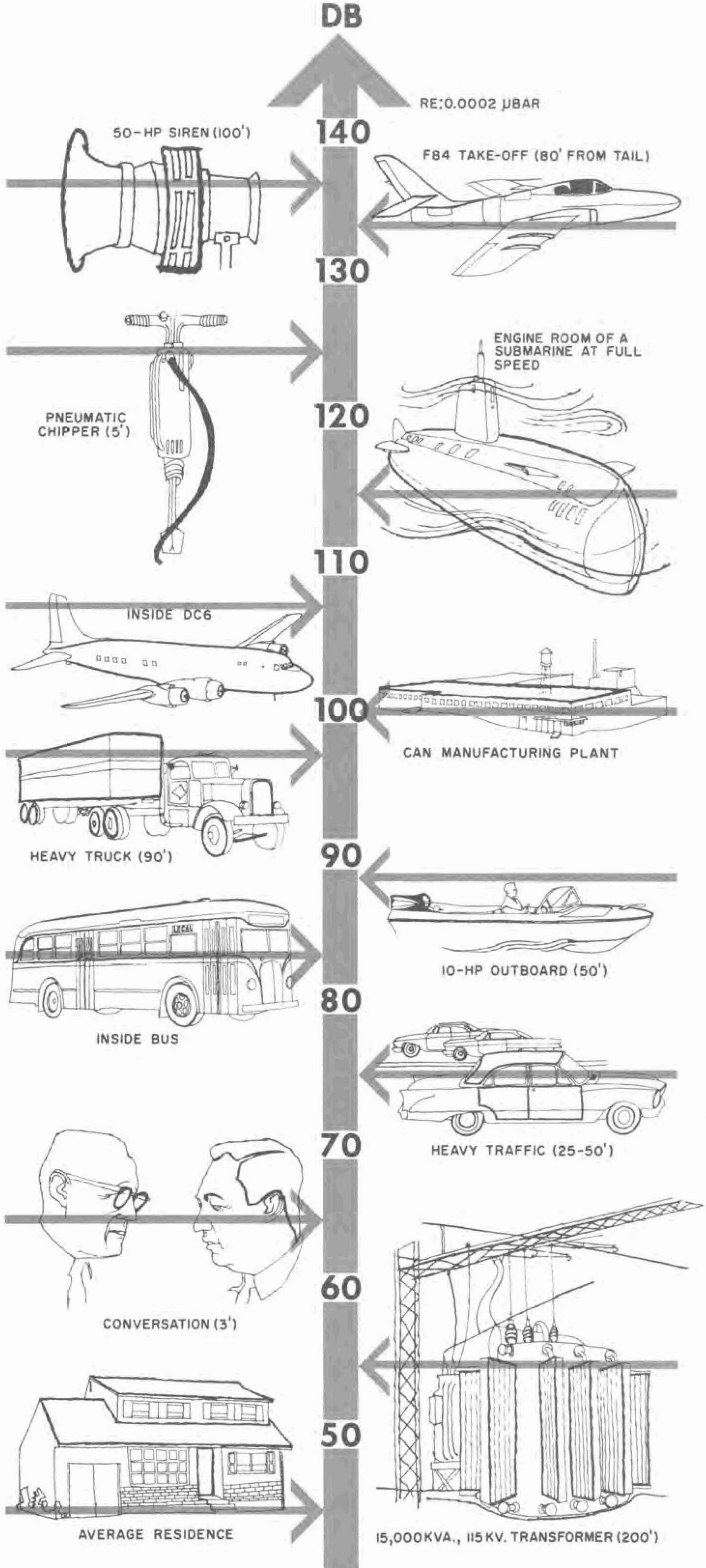


Fig. 3. Some typical noise levels. Figures in parentheses indicate the distances from the noise sources to the sound-level meter.

attenuator switch setting that is used.

As you can see, manipulating the controls of a sound-level meter is child's play. Positioning the microphone properly, determining the effects of background noise, and deciding which weighting network to use are slightly more complicated. And interpreting the results, assessing the validity and significance of data—these are things that take noise measurement out of the little-league class.

Microphone Placement

Most microphones used in sound measurement are essentially non-directional at low frequencies, but show some directional effects up where the size of the microphone is comparable to the wavelength of the sound in air. Fig. 4 shows how the response of a typical measurement microphone varies with the incidence with which the sound strikes. Note a possible difference of 8 db between 0 and 90 degree incidence at 8000 cycles. Given a microphone with such response, you would place it to receive the sound at a grazing (90°) incidence, since the 90° curve is the flatter of the two responses.

There is a natural tendency for the measurer to face the noise source, holding the sound-level meter in front of him as if he were taking a snapshot of the noise. By "backstopping" the noise in this way, the measurer distorts the measurement. The recommended posi-

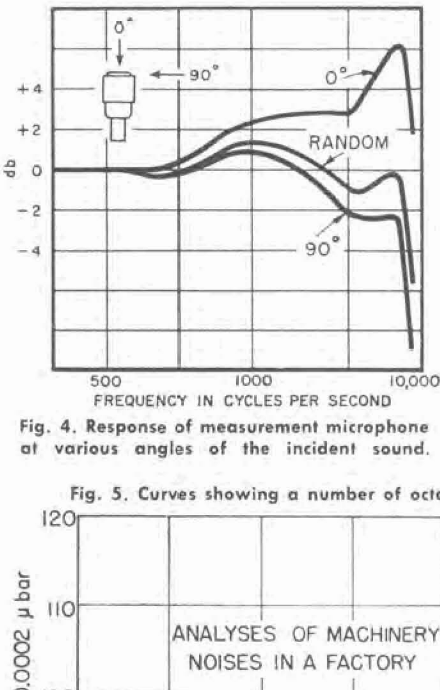


Fig. 4. Response of measurement microphone at various angles of the incident sound.

The sound-survey meter is small, easy-to-use, and battery-powered for portability.

tion is to one side of a line from noise source to microphone, with the measurer facing in a direction perpendicular to the noise path. Better still, remove the measurer from the microphone entirely, by using a tripod and extension cable.

If you're concerned with the noise level at one particular point only, that point is obviously where you make at least one of your measurements. If you're evaluating the speech-interference or hearing-damage capabilities of the noise, you would place the microphone where the subject's ear would normally be (but with the subject out of the way, where he won't interfere with the measurement).

Test codes on apparatus noise measurement specify the places of measurement, and the American Standard Test Code for Apparatus Noise Measurement points out the wisdom of exploring the noise field before deciding on microphone locations.

One more thing on microphone placement: Keep it out of the wind. Wind on the microphone produces a low-frequency noise that can seriously affect measurements. One way of reducing the effect is by use of a wind screen.

Weighting Networks

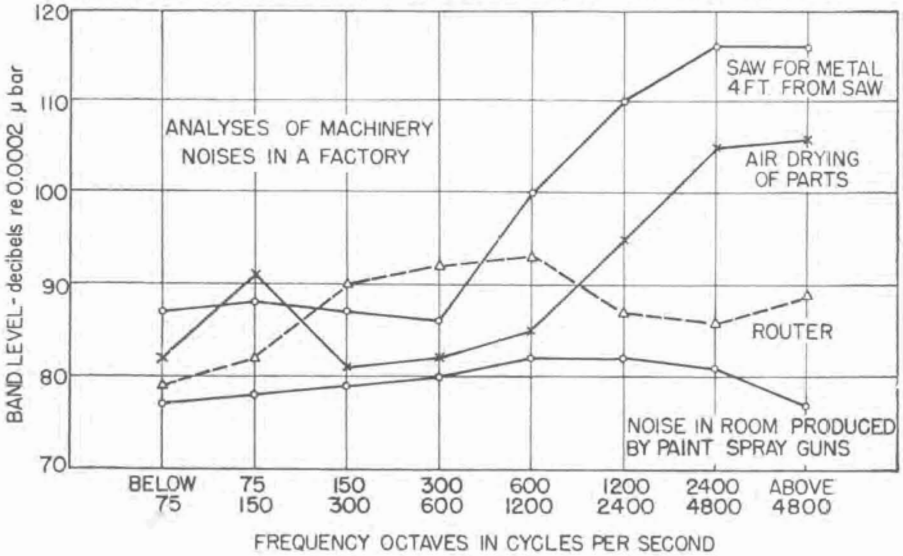
As mentioned earlier, any realistic noise measurement must take into account the frequency-response characteristics of the human ear. This is the historical foundation for the weighting networks found in all sound-level meters, although no one today suggests that weighting networks actually translate raw sound pressure level into the subjective notion of loudness. There are three ASA-specified weighting networks, whose characteristics are shown in Fig. 2. Some authorities suggest selection of weighting networks on the basis of the range of levels to be measured (*e.g.*, *B* weighting from 65 to 75 db). Some advocate the use of *A* weighting for comparison of noises of different types, and certain noise-test codes specify the weighting network to be used in all cases. Perhaps the wisest course is to measure and record levels on all three weighting networks. For one thing, the three figures can be used to produce a rough frequency analysis.[1] For another, it is always a good idea to store such data; you never know when you might want it.

Now that you have measured noise level, what do you do with it? Well if a test code specifies that the *B*-weighted level should be less than 80 db and you've measured it at 85 db, you know that the test has been flunked. Or you might have made the measurement to see whether certain noise levels are likely to cause hearing damage, in which case you might compare your findings with suggested criteria.[2]

But for many noise measurements, the sound-level meter by itself is not enough. Too much depends on the frequency distribution of the noise, and thus the octave-band analyzer has become the second tool of the trade.

The octave-band analyzer measures the noise level of any of eight ASA-specified frequency bands. These bands are: 20-75, 75-150, 150-300, 300-600, 600-1200, 1200-2400, 2400-4800, and 4800-9600 cps. These octave-band levels can be used to compute loudness level in phons.[3] Also by taking the average of the

Fig. 5. Curves showing a number of octave-band analyses of common factory noises.



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1. Peterson & Gross: "Handbook of Noise Measurement," General Radio Company, West Concord, Mass. Fourth Edition, page 35 (after Cox).
2. We recommend that those concerned with noise-induced hearing loss request the latest information on this subject from the Research Center, Subcommittee on Noise of the Committee on Conservation of Hearing, American Academy of Ophthalmology and Otolaryngology, 327 S. Alvarado St., Los Angeles 57, California.
3. Stevens, S. S.: "Calculating Loudness," Noise Control, Vol. 3, No. 5, September 1957, pages 11-22.

noise levels in three octave bands (600-1200, 1200-2400, and 2400-4800), you come up with the Speech Interference Level (SIL) of the noise, which you can compare with published criteria to find out the extent to which noise will interfere with conversation. The octave-band analysis offers still another way of rating noise, by Noise Criterion (NC) value,[4] sometimes used to evaluate acoustic properties of offices, school rooms, auditoriums, etc. Finally, octave-band levels can be converted to Noise Rating,[5] used to evaluate noise levels in residential areas.

An octave-band analysis, as you can see, is an essential part of most serious noise studies. Fig. 5 shows such an analysis of various noises in a factory. Growing in favor is the third-octave-band analyzer, which divides the over-all frequency range into three times as many bands as does the octave-band analyzer, and consequently gives more information (and takes more time).

A normal sound-level measurement is usually not adequate for impact noises. On a drop-forge impact, for example, the peak level may be as much as 30 db above the maximum reading that would appear on a sound-level meter. An oscilloscope could be used to show more complete information, such as rise and decay rates, but the technique is involved. Much more convenient is the impact-noise analyzer, which can measure peak value, instantaneous level, and a time-averaged level of the noise.

Standards for noise measurement are constantly changing as scientists gather new data. The best way to learn about human reaction to noise is by experiment, and the more subjects, the more useful the results are likely to be. Improved test procedures and larger samplings often force scientists to revise the standards. For this reason, and because the idea is good scientific practice, it's important to keep detailed records of all measurements. A complete record will probably include data of no apparent significance, but you never know what tomorrow's standards may bring. Here's a list of things you might record:

1. Description of the space where the measurements were made (nature and dimensions of floor, walls, and ceiling; description of nearby objects and personnel).

2. Description of noise source (dimensions, nameplate data, location, type of mounting, and operating conditions).

3. Description of secondary noise sources (location, types, kinds of operations).

4. Type and serial numbers of all microphones and instruments used.

5. Positions of observer.

6. Positions of microphone (direction of arrival of sound with respect to microphone orientation, length of microphone cable).

7. Temperature of room and of microphone.

8. Results of maintenance and calibration tests.

9. Weighting network and meter response.

10. Measured over-all and band levels at each microphone location.

11. Background over-all and band levels at each microphone position (*i.e.*, with primary noise source shut off).

12. Cable and microphone corrections (for temperature and humidity, as specified by manufacturer).

13. Date and time.

14. Name of observer.

The more useful information you record, the better off you'll be in the next phase of the noise-control program. That's when you decide what to do about the noise you have just measured. Techniques of noise reduction constitute a story in themselves, beyond the scope of this article. After you've put rubber feet on the machine or changed motors, or installed sound-absorbing material, you'll want to re-measure to be sure of the improvement. Obviously, the before-after comparison will be most meaningful if the second set of measurements was made under the same conditions as was the initial set—another reason for keeping detailed records.

In the war against noise, careful measurement pays off. And the pay-off is a precious commodity that too often seems to be going out of style—quiet. ▲

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4. Beranek, L. L., ed.: "Noise Reduction," McGraw-Hill Book Co., 1960.

5. Rosenblith, W. A. & Stevens, K. N.: "Handbook of Acoustic Noise Control," Vol. II, "Noise and Man," WADC Technical Report 52-204, PB111274, Office of Technical Services, Department of Commerce, Washington 25, D.C., June 1953.

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