Using psycho-acoustic analysis to characterize product noise

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It's been said that the 20th century is not simply the age of industry, but the age of noise. No matter where we work, where we live, or what we do, noise surrounds us. Increasingly, product manufacturers must measure, quantify and analyze acoustic noise of their products to better meet noise standards and remain competitive in today's marketplace.

It makes no difference if you're designing automobiles, office products, or industrial machines. Your challenge today isn't simply to make a better mousetrap—it's to build one that's also quieter.

Basic sound measurements

Product noise characterization is based on two essential measurements—*sound power* and *sound pressure.*

Sound pressure is how we hear. It's the movement of our eardrums in response to tiny changes in atmospheric pressure as sound reaches our ears. Sound pressure is a measure of sound only at one point in space because it varies with the distance from the source (and it diminishes by the square of the distance as we move away from the source).

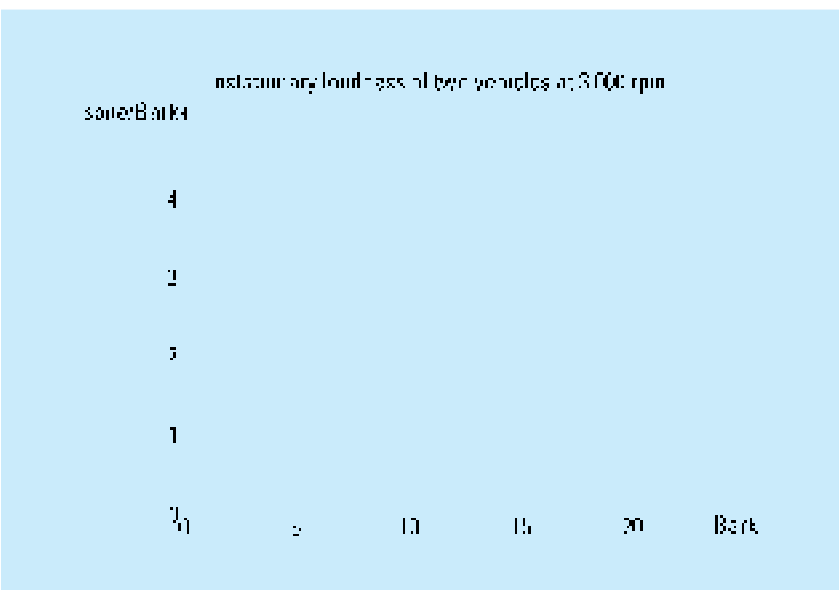

Figure 1
Comparing instationary loudness of two vehicles at 3,000 RPM.

Sound pressure is easy to measure. Portable sound-level meters have been around for many years and while useful, they don't provide enough information for product development. Sound-level meters indicate "how loud" noise is, but they don't reveal any frequency information—a sound-level meter is essentially a voltmeter that responds over the entire range of human hearing. Spectral analysis of sound requires an octave analyzer or a spectrum analyzer (some instruments can do both, using FFT-based DSP technology).

Sound power is the only true measure of a product's noise output. For many years, the only way to measure how much noise a device made was to bring it into a completely "dead" room (an anechoic chamber) and take a series of averaged sound pressure readings to estimate sound intensity from the device. This technique works well but has many limitations. For one thing, the device-under-test has to be small enough to fit into the anechoic chamber. Also, there aren't many anechoic chambers (they're costly to build), so test time is normally very expensive.

Within the last 20 years, sound-power measurements without using anechoic chambers have come into use with the development of sound-intensity techniques. These use a special two-microphone probe that uses both phase and magnitude information to minimize the influence of reflected or external sounds. Additionally, sound-intensity measurements are used to locate the source of specific noise components, making them extremely useful when troubleshooting noise problems for large, complex machines.

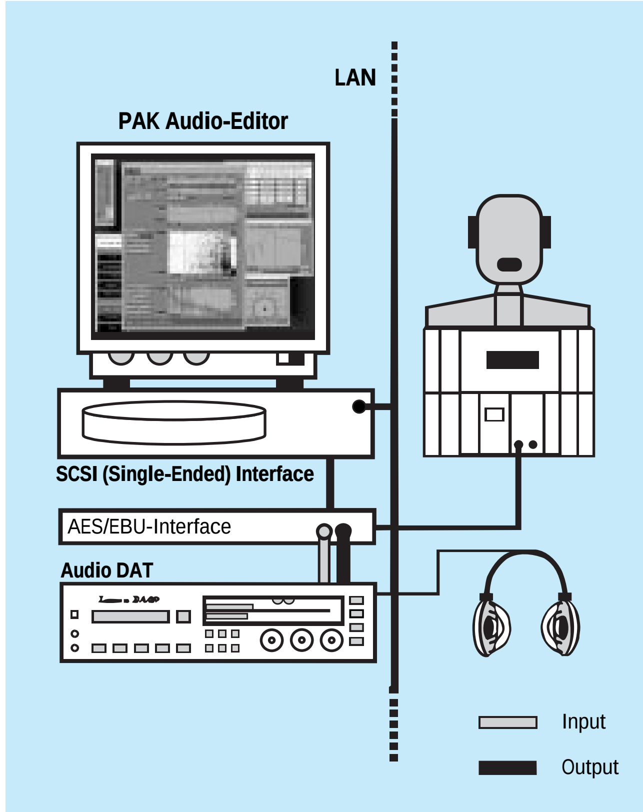

Figure 2
The PAK 2-Channel Audio Data Analysis System is based on the Hewlett-Packard Series 9000 workstation and a digital audio tape recorder.

Limitations of simple sound measurements

Because tests in anechoic chambers were so expensive, for many years simple sound-level tests (using portable meters) were the only noise measurements generally made. While helpful, these measurements didn't reveal enough information to quantify how people reacted to a particular noise signature. Some noises, while seemingly low-level when measured with sound-level meters, were actually much more annoying to people than other noises that measured louder.

Early on, researchers recognized the limitations of simple sound-level meters and did attempt to gather frequency information as well. By the late 1940s, rudimentary 1/1- and 1/3-octave analyzers were available. For the first time, acoustic consultants and design engineers could measure noise and characterize predominant noise components. Within the next two decades, noise analysis (in one form or another) became commonplace as engineers used it to design quieter buildings and products—quieter factories, ventilation systems, machine tools, airplanes, automobiles, trains, buses, communications systems—practically every conceivable product or process.

We don't hear noise the same way we measure it

Much of what we know about how the human ear responds to sound was done by telephone engineers (notably Fletcher and Munson at Bell Telephone Laboratories in the United States, and by Barkhausen in Germany). During the 1920s and '30s, these researchers discovered that the human ear does not respond linearly to sound. In fact, our sensitivity to sound is more acute for frequencies that are between 2000 Hz and 5000 Hz, and this sensitivity varies as the overall sound level increases or decreases. Thus "weighting filters" were developed to ensure that sound level instruments responded more like the human ear. In English-speaking countries, the "A-weight" curve is used since it approximates how we hear low- to medium-level sounds (other weighting filters are used for louder sounds, such as jet engines). Similar weighting filters are used in other countries.

The use of weighting curves for sound-level measurements was an important first step, but weighted measurements still don't reveal enough to explain why some noises are more annoying than others. Often, reducing the components that contribute the most to "annoyance" is often more important than reducing the overall noise level. A good example is the acoustic engine response inside a car as the driver increases speed. The goal is to get a characteristic but pleasant sound response and not one that is annoying. Unfortunately, frequency information from 1/1- and 1/3-octave measurements provides only the most basic clues for designers as they struggle to make products that are more pleasant.

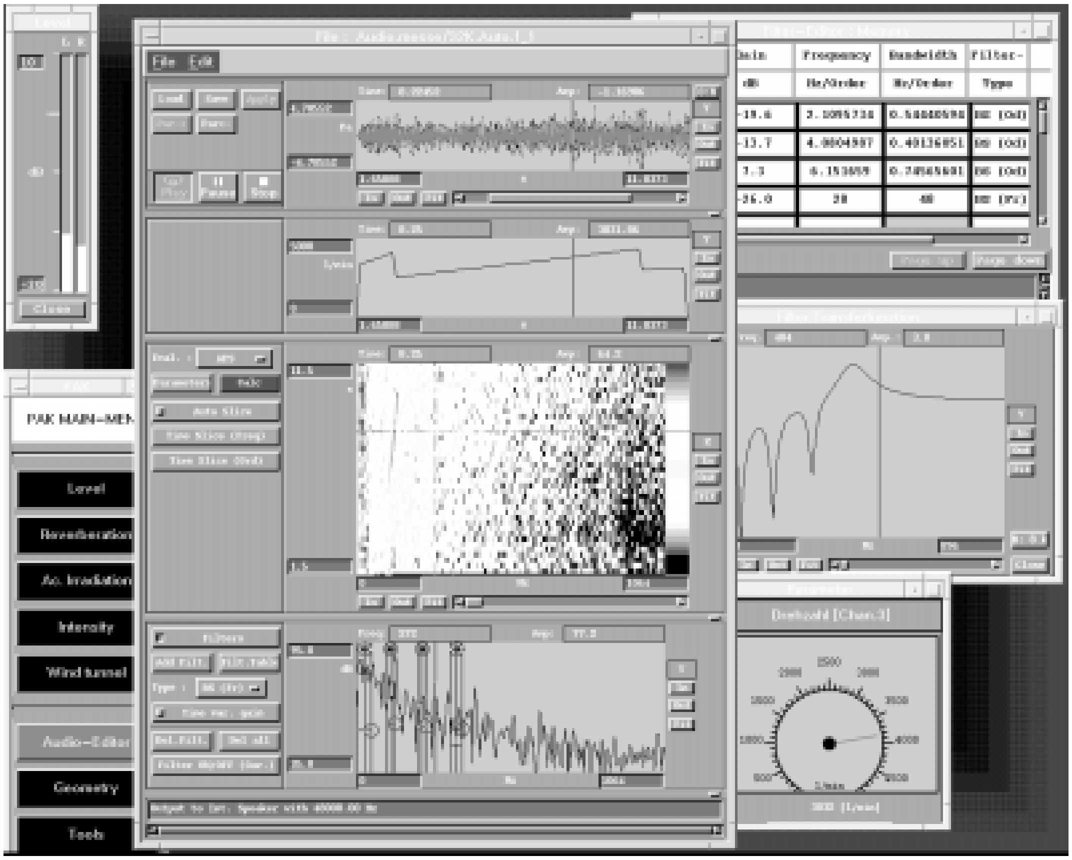

Figure 3
Engineers modify recorded time histories by applying filters and listening to the effects with the PAK acoustic design tools.

Psycho-acoustics *quantifies* our reaction to noise components

Psycho-acoustics uses the most current understanding of human hearing and the psychological effects of noise to measure, quantify and identify key components of a noise signal that must be reduced to diminish their annoyance to the human ear. Psycho-acoustics isn't new, but it's become remarkably sophisticated within the past few years, in part due to new research in the field and to improvements in signal-processing technology. Basic psycho-acoustics measurements deal with four "hearing sensations"—*loudness, sharpness, variation (fluctuation strength)* and *roughness*.

Instationary loudness (see figure 1) is a measure of the magnitude of noise volume and also reflects the time and spectral masking effects characteristic of the human ear. It is measured in *sones* (from the Latin word *sonare*, "to sound"). A *sone* is referenced to a 1 kHz tone at 40 dB_{SPL}. A noise that appears to be twice as loud as this reference would measure 2 sones.

Sharpness is used to characterize steady-state noise, and is a measure of the proportion of loudness within critical frequency bands. For example, two different types of noise may have equal loudness, but the one with greater sharpness will have louder frequency components within frequency bands to which the human ear is particularly sensitive (in the world of music, the “timbre” of a sound is related to its sharpness). Sharpness is measured in *acum* (from the Latin word *acer*, “sharp”). An *acum* is referenced to a narrow-band noise centered at 1 kHz with a level of 60 dB_{SPL}.

Fluctuation strength (sometimes called “variation”) is used to characterize dynamic noise by measuring the temporary deviation of the loudness spectrum due to frequency modulation between 0.25 Hz and 20 Hz. Fluctuation strength is measured in *vacil* (from the Latin word *vacilare*, “vacillate”). A *vacil* is referenced to a 1 kHz tone at 60 dB_{SPL} that is frequency-modulated by a 4 Hz sine wave with a modulation factor of one.

Roughness is used to characterize dynamic noise by measuring the temporary deviation of the loudness spectrum due to frequency modulation between 20 Hz and 300 Hz. Roughness is measured in *asper* (from the Latin *vox aspera*, “rough voice”). An *asper* is referenced to a 1 kHz tone at 60 dB_{SPL} that is frequency-modulated by a 70 Hz sine wave with a modulation factor of one.

Solutions for psycho-acoustic analysis

As you can imagine, the kind of processing power required to apply psycho-acoustics analysis to noise measurements made it cost-prohibitive until recently. But today, powerful DSP workstations have made the technology available to leading companies around the world. One such system is PAK, an acoustics test stand developed by the German firm Mueller-BBM GmbH (see figure 2). This uses an HP 3587S VXI workstation to form the core of a powerful acoustics test system that includes psycho-acoustics.

The PAK system makes sophisticated noise measurements, then lets designers view (and listen to) effects of proposed acoustic treatments without having to modify the device-under-test. In addition to the psycho-acoustics software module, PAK includes modules for tracked analysis, including FFT, digital nth octave and digital order analysis. The Audio Editor is a tool for acoustic design (allowing designers to listen to and simultaneously modify the sound signal with digital filtering), A/B comparison, mixing, cutting and synthesis (see figure 3). Other modules include reverberation, operational deflection shape analysis, acoustical irradiation and intensity measurements. The system provides scaleable hardware and software for multichannel applications up to 256 inputs. ■

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