SOUND QUALITY, PART THREE: SOUND QUALITY LOCALIZATION TESTING

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In Part II of this series, the concept of sound quality subjective testing, binaural recording and jury process were discussed.

The concept underlying Part II was that technical acoustics is not the primary issue in sound quality work; rather, the use of sound quality as applied to product design is interested in predicting purchasing and other response behavior from subjective jury testing of responses to product noise.

In Part III, we will discuss the concept of source localization, starting with the acceptance of a sound quality product standard. While our past articles have concentrated on the development of sound quality standards, this article considers what happens once a preliminary or final sound quality standard is accepted and existing or new products are analyzed for their performance under that standard. The specific examples of testing and analysis systems included in this article are based on those supported by the Sound Quality Working Group, noted in previous articles. They are shown as significant illustrations of the process of sound quality measurement.

The standard may be based on frequency response, time-based response and even on product vibration. It may be characterized as a change in sound quality of an existing product or as a totally synthesized sound quality standard based on either an existing or a new product. This standard will take into account the question of significance (will response of the consumer actually change in beneficial ways via environmental factors, such as signal-to-noise ratio and other counterveiling stimuli?).

THE SECOND ENVIRONMENT PROVIDES THE NOISE FLOOR AND SIGNAL DISTORTION AGAINST WHICH THE SIGNIFICANCE OF THE MEASUREMENT IS LATER JUDGED.

In the process of accepting the sound quality standard in place, the research and marketing departments may have made some assumptions regarding these issues:

- The consumer value, in dollars, of the standard.
- The research and manufacturing cost of the potential changes.

It is important to remember that as the product analysis and diagnostic testing and design proceeds, the program may be found to have violated these limits and may then need to be reassessed.

Typical questions arising at this testing phase of a sound quality project are these:

- What is the current spectral description of this product?
- What is the current temporal description of this product?
- When comparing these with SQ goals, is this problem attenuation-based (noise reduction) or more complex *(i.e., altering a changing signal, etc.)*?
- Is the product "SQ" objective narrow (narrow band analysis) or wider (1/3 octave or greater)?
- What kinds of analysis capabilities are available and are they sufficient?
- Is the in-house staff aware of and conversant with the sound quality process?

Often, these questions very quickly move the manufacturer to make a series of decisions regarding testing systems, additional training of staff and the use of outside testing laboratories.

Since a sound quality analysis system typical of those described in these articles may cost $200,000 or more, the manufacturer may decide to outsource some or all elements of the formal sound quality program, most commonly binaural recording and editing, jury testing and complex system testing (intensity and modal analysis). Additionally, many manufacturers come to the conclusion that involving their own staff with an

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outside sound quality laboratory is often the quickest, least expensive and most dependable source of training available.

With this brief introduction, this article is focused at providing an introduction to the physical testing of the product to determine what components are causing SQ problems and what changes are needed to bring them into compliance with the standards in place.

THE PRELIMINARY MEASUREMENT INVESTIGATION

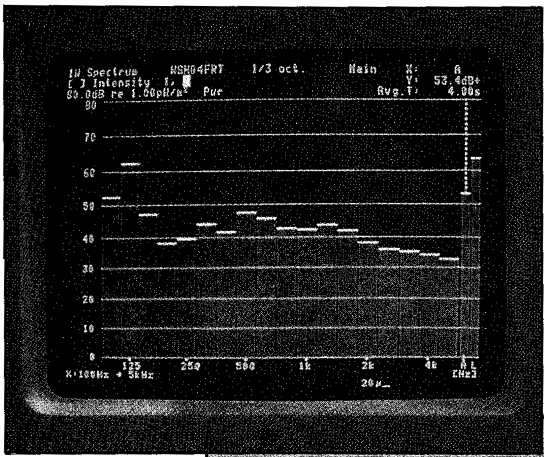
As the new sound quality standard is considered, one of the first steps is to determine organizational measurement and calculational capabilities. In terms of testing capabilities, the typical inventory of test systems includes:

- Precision sound level meters
- Precision microphones
- Real time analyzers
- Narrow band analyzers
- Accelerometers
- Impact hammers
- Dual channel analyzers (FFT and discrete filter)
- Intensity software
- Modal software
- Finite element analysis software
- Operational deflection shapes software
- Wavelet transform software
- Specific sound quality analysis software

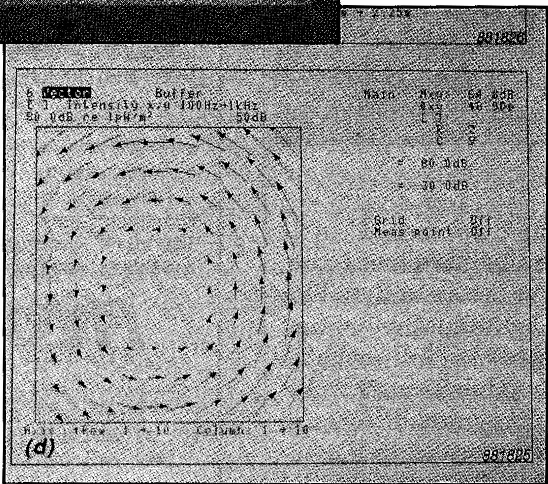
In terms of test spaces, the in-house lab generally has a hemi-anechoic (absorptive walls and ceiling plane) or near hemi-anechoic room; some are equipped with full anechoic chambers (absorptive floor as well). In terms of testing capabilities, the firm should have a working knowledge of sound intensity testing, modal analysis (to analyze structurally based sound generation) and computer modeling techniques. If the client is looking for a basic set of information on these issues, some sources include the membership and committees of the Acoustic Society of America (ASA), the International Standards Organization (ISO), the American National Standards Institute (ANSI), the Audio Engineering Society (AES), the Society of Automotive Engineers (SAE), the American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), the American Psychological Association (APA) and the American Speech and Hearing Association (ASHA).

THE EXPERIMENTAL PROCESS

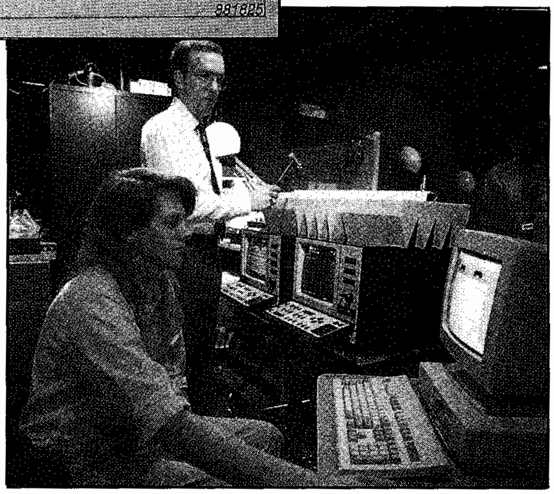
The process of evaluation of the product in question suggests consideration of two kinds of testing environments; the first is the anechoic or "dead" room, and the second is the typical use environment of the product (or its simulation). The first environment provides results with the best signal-to-noise ratios and lowest distortion, and the second environment provides the noise floor



Bruel & Kjaer 2133 Intensity Analyzer display.



Intensity displayed as a Vector Map.



Modal Testing with Impact Hammer.

and signal distortion against which the significance of the measurement is later judged. Prior to beginning the testing process, the technicians involved should very carefully review the sound quality standards data.

Additionally, and very importantly, they should review, by listening, the progression of tapes recorded in the process of developing the sound quality standard. This eye on subjective performance is very important as the process moves along, as recognition of appropriate sound characteristics by the ear is a substantial aid to the measurement analysis of the sounds in question. (Psychoacoustic analysis is often very complex and does not easily correlate with the mass of data which can be gathered.) As audio researchers know all too well, the current profusion of testing equipment uses the term "analyzer" quite loosely. The large quantities of data developed during the testing process goes through no intelligent analysis within the basic test system; the analysis is up to the user.

MEASURING THE DEVICE

The first measurements made of the device are generally measurements of the spectral output, and these are typically made on an FFT or a Real Time Analyzer.

The FFT or constant bandwidth analyzer provides a linear measurement of the sound spectrum, generally from 20 Hz to 20 kHz. The constant percentage bandwidth analyzer or constant energy bandwidth analyzer (also called the real time analyzer due to its instantaneous measurement of all frequencies) provides information in the same frequency range, but it is provided in octaves or fractional octaves ($^1/_1$, $^1/_3$, $^1/_{12}$, $^1/_{24}$, etc.) Its data display is logarithmic.

The first of these analyzers is most typically used in vibration studies (due to its capability to measure pure tones, etc.) although many of these systems can synthesize octave-based data for display. The second analyzer is generally the more popular system for acoustical measurement, as it better represents the ear's perception of sound in its octave-based, logarithmic display. Often, a recorder, such as a DAT recorder, is used with or in lieu of the analyzer. This allows collecting data in an unanalyzed form for later alternative analyses.

The spectral data gathered will next be compared with spectral information in the new standard to determine what level of enhancement or reduction is needed. Via this process, it may be discovered, for example, that there is an excess level at 2500 Hz, and that this excess is 12 dB. With this in mind, the question arises as to the source of this discrete frequency component, and this is an ideal problem for intensity analysis.

INTENSITY MEASUREMENT

Intensity measurement is not new (see Sound & Communications, June 1989, July 1989, September 1989); it has been applied to product analysis for about 10 years by some practitioners. Intensity analyzers are dual channel analyzers with directionally sensitive, and generally dual, microphone probes. In addition to normal acoustic measurements, they are capable of measuring and plotting the directional flow of sound power. The display on the screen is typically in two colors in order to indicate positive and negative intensity (sound coming from in front of or behind the probe).

In addition to the ability to display the positive and negative intensity of each frequency, there is a very powerful capability provided in the more advanced analysis systems and software. This is the capability to display data of grided measurements as number maps, contour maps, 3-D maps or vector maps. It is this capability to provide scientific visualization of the sound flow which is so crucial in the analysis process.

In order to gather this type of "gridded" data, a physical grid of string is generally set up and placed sequentially on each side of the product under test. The spacing of this grid, its distance from the product, the choice of microphones and spacers (cylinders establishing the distance between microphones on the intensity probe), the time constant of the measurement and the bandwidth limit of the measurement (octave, 1/3 octave, etc.) is based on experimental data gathered from measurement manuals and trials with the products to establish the necessary measurement resolution.

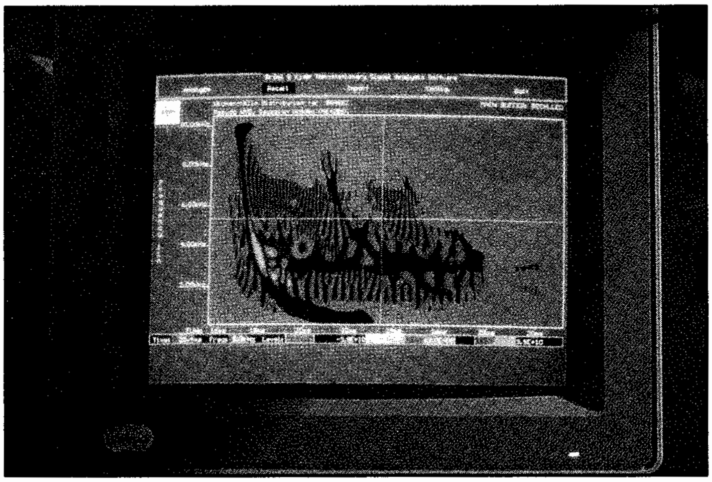
Once these data are gathered, generally by manual or automatic input to the analyzer, they are transferred to a calculational program in order to produce the visualization maps. Next, these maps are often overlaid on the specific engineering drawings of the product in order to see where the sources of noise are originating from. Measurements can be made across a broad frequency spectrum, and displays can then be generated as broadband displays or as displays of the frequency region of interest in bandwidths as narrow as 1/12 octave.

Once these preliminary measurements are taken and plotted on the product drawings, a logical analysis must be applied in order to determine their meaning. If, for example, components for silencing are easily identified via this mapping, then the analysis may be sufficient prior to working with these components. Alternatively, the mapping may require trial and error in terms of selecting frequency regions and resolution which provide meaningful conceptual pictures of component operational problems.

VIBRATIONAL MEASUREMENT AND OTHER TOOLS

Once the analysis of source localization has been completed, individual components may be analyzed via the same intensity procedures, and are mapped in great detail. In the analysis process, it is often discovered that an individual structural component is providing the offending acoustic signal due to its inherent structural properties or modes. In this case, finite element analysis (FEA) may be employed. FEA is a method of computer modelling the structural behavior of the device or component in question mathematically, in order that a theoretical view of specific modal problems may be developed. Following upon FEA or in lieu of this testing, individual components may be analyzed via modal analysis (MA). Modal analysis is used as a method of exciting the component under test, either via the use of an impact hammer or via the use of a structural shaker.

Modal testing is accomplished via the use of an excitation device, an FFT analyzer of the requisite number of channels, and charge amplifiers powering measurement accelerometers. As with acoustical intensity testing, the results are often taken on a DAT recorder for later alternative analysis. During this test-



Wavelet transform display.

ing, accelerometers (vibration transducers) are placed at various positions on the component under test in order to construct a vibrational mode shape visualization of the component. In addition, the structure is also driven at various positions.

After the testing has been completed, modal analysis software is employed to build a model from the data (or to correct the analytical model) in order to understand the vibrational characterization of the product. Findings from this work often suggest changes in structural materials, structural damping and reinforcing, etc.

Additional methods of analysis include use of the Wavelet Transform, a method of topographical visualization of level, frequency and time, and Operational Deflection Shape Analysis (ODS), a method of visualizing the operating modes of a structure under active operation (without stimulation from a hammer or a shaker).

SUMMARY

With this general background in diagnostic testing, the process of sound quality broadens out into its full continuum. This last phase requires substantial knowledge of the testing process along with substantial investment in testing instrumentation and capabilities. It is also the phase that ties together the entire process of sound quality analysis. While there are many methods of conventional and binaural recording, it is important that the data developed in the recording process be compatible with that developed in the diagnostic process. Thus, it is not sufficient to talk about sound quality as only the recording and jury process. This is why our original binaural recording system development used both a recording torso and a measurement torso and analyzer. (See Sound & Communications, September 1990, October 1990.)

In the sound quality process, we have now come full circle from the audio field (recording/editing) through the field of perceptual psychology (jury assembly and testing), through complex acoustics and vibration, and by implication, back to audio and psychology (final listening verification). This journey would be tenuous at best if it were not for the fact that we use as a basis for validity the human listener and the predictability and repeatability of his response.

Next, we will consider a number of examples of sound quality projects in order to more significantly demonstrate the application of this practice to the real world. ■