Vac. motor drives generator located in enclosure (with load dumped to heater)

Close-up showing drive belt & tech rig

Test rig also includes motor for driving rotating beater brush

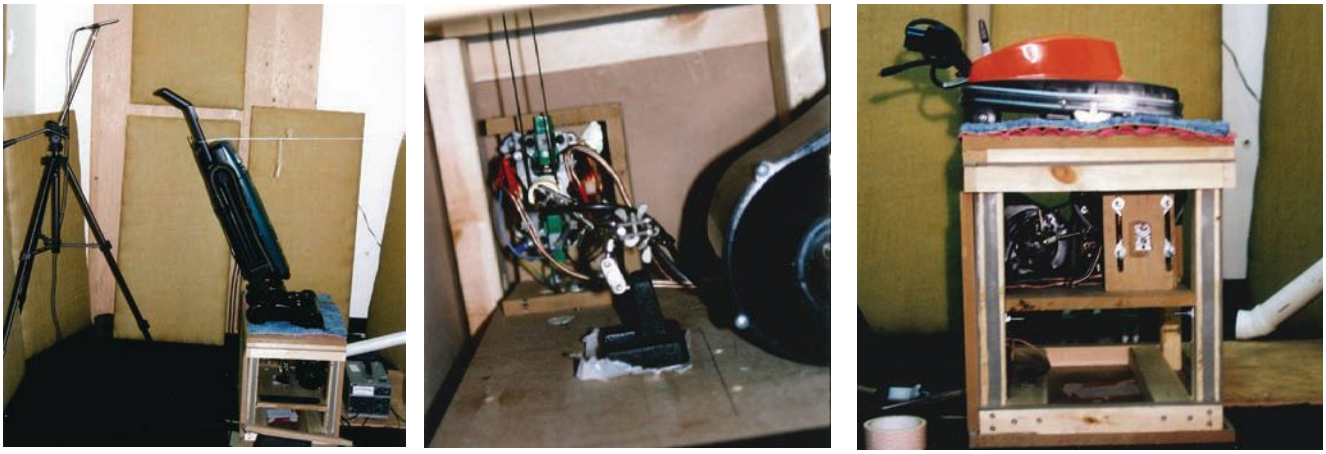

Figure 1: Use of a specialized test rig to impart representative loading on vacuum cleaner motor. *Source: Acentech*

USE OF "NOISE AUDITS" IN CHARACTERIZING AND REDUCING APPLIANCE NOISE

by david l. bowen

Appliances and other consumer products often share some common traits that impact both the acoustical measurement techniques that can be employed to characterize their noise output, as well as the noise control options available. These traits include their relatively small size, low profit margin, and quick time to market. Their small size implies that existing units or prototypes can usually be set up for acoustical measurements and evaluations inside a modestly sized, easy to build reverberation room. Low profit margins imply that design solutions, rather than the addition of "acoustical" materials, constitute the preferred route to a quieter product, but the quick time to market can sometimes work against this approach.

This article describes a sound power based "noise audit" method for characterizing and rank-ordering the potential noise sources in an operating device, where information gained from the audit can be used to devise the most effective noise reduction strategy to pursue. The use of this engineering technique is illustrated for the particular case of appliances, where the design trend is often towards lighter, stiffer components and faster rotating parts, all of which tend to increase noise.

Motivation

There are some common traits in appliances that have a direct impact on the way we can go about measuring and, ultimately, reducing their noise.

First, all are relatively small in size, which implies that we can make use of a modestly sized reverberation room (on the order of 100 m^3) for the purpose of characterizing the total sound power output from the appliance (although tones at 120 Hz and below may be problematic in a smaller room). A reverberation room is especially suited for engineering evaluations such as performing quick, comparative measure-

Information gained from the audit can be used to devise the most effective noise reduction strategy.

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(vacuum cleaner wrapped in lead)

motor & impeller uncovered

Figure 2: "Window method" being used to obtain component noise levels in another vacuum. *Source: Acentech*

ments to determine the effect of making changes. The footprint and height of such a room can usually be accommodated within the existing engineering facilities at a product manufacturer.

Another common trait is low profit margin, which discourages the use of "add-on" treatments/ materials for noise reduction due to their recurring cost, and instead favors re-design of parts and mechanisms for reduced noise. Another implication of low profit margin is a tendency towards high variability in the noise of parts, which means that care has to be taken to ensure that enough samples are included when evaluating noise.

Appliances usually share another trait, which is a quick time to market. In contrast to low profit margin, the short design/build cycle may encourage the use of add-on materials and discourage what can be a longer-term process of redesign.

All of these traits provide motivation for the "noise audit" approach of characterizing appliance noise, since the emphasis on redesign/modification of parts leads to a need to first characterize the noise from each part (e.g., the "audit") before embarking on a general noise reduction program. In addition, the reverberant room method provides an easy, consistent way to determine the sound power output associated with each part/mechanism in the product.

The Noise Audit Process

The first step in the audit process is to identify or group together the potential noise producing components or mechanisms. Examples of such sources may include the noise directly radiated by, say, a motor when under load, "structure-borne noise" due to vibration transmitted from this same motor to various connected structures, the blade passage tonal noise associated with a cooling fan, noise due to gear mesh, noise due to airflow, etc.

The next step is to determine the noise produced by each individual source (when placed, for example, in a reverberant test room). The most straightforward way to do this is to operate a source by itself while maintaining representative speed, load, temperature, etc. When this is not possible, other methods can be employed such as the "window" method whereby all sources but one are attenuated by means of passive enclosures, wrappings, silencers, etc. Other

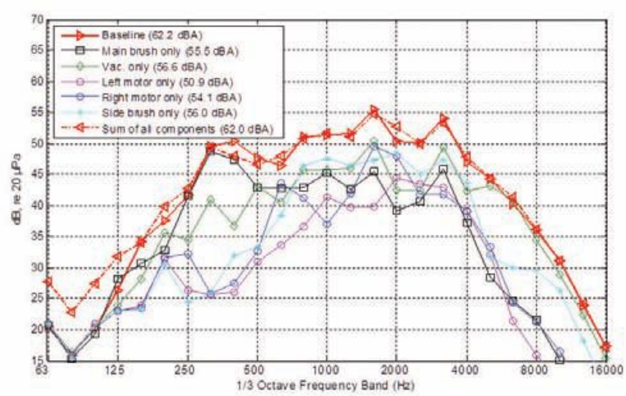

Figure 3: A-weighted 1/3 octaveband frequency spectra of noise source components operated individually in a vacuum cleaner, along with comparison of measured baseline and sum of sources. *Source: Acentech*

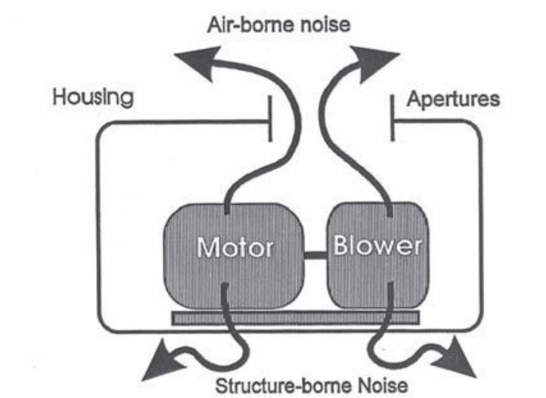

Figure 4: Schematic layout of a consumer product showing sound sources and transmission paths. This schematic may represent a wide variety of products such as appliances, power tools, etc. *Source: Acentech*

Sound Source Component	Current Sound Level, dBA	Proposed Reduction, dB	New Sound Level, dBA	Comments
Motor, Airborne	76	6	70	Reduction of air turbulence needed in addition to new motor cooling fan. Is it possible to increase fan efficiency and reduce cooling demand?
Blower, Airborne	75	5	70	Muffling higher freq. airflow noise will readily achieve the goal, but is space available?
Motor, Structure-borne	77	7	70	Softer isolation mounts may help, but the low surface-weight density of the housing will make this NR difficult. Permanent wrapping of housing too heavy – not acceptable.
Blower, Structure-borne	72	2	70	Slightly softer isolation mounts will likely achieve this modest reduction.
Total	82	6	76	May require redesign of the motor and blower themselves.

Table I: Balanced design approach for obtaining an overall reduction of 6 dB. *Source: Acentech*

Sound Source Component	Current Sound Level, dBA	Proposed Reduction, dB	New Sound Level, dBA	Comments
Motor, Airborne	76	7	69	Reduction of air turbulence needed in addition to new motor cooling fan. Is it possible to increase fan efficiency and reduce cooling demand?
Blower, Airborne	75	7	68	Additional muffling space required to reduce the sound of the lower freq. blade passage tone. Product usability may be compromised.
Motor, Structure-borne	77	4	73	Replacement of isolation mounts and the addition of softer aperture/ housing connection will achieve this goal
Blower, Structure-borne	72	4	68	Softer mounts plus adding mass at mounting points will help, but will mass increase be acceptable?
Total	82	6	76	Trades off slightly more reduction of airborne noise for less reduction of motor structureborne noise

Table II: Another strategy for obtaining an overall reduction of 6 dB. *Source: Acentech*

methods involve determining source levels from narrowband frequency spectra if the frequency range of the source is unique (such as a tone or set of harmonics from a periodic source), employing sound intensity measurements, using a vibration shaker to simulate certain source mechanisms, or subtraction of weaker source levels if the weaker sources can be measured but a more dominant source cannot. Sometimes it is not possible or feasible to determine the absolute level of each and every source, but even in these cases we can usually at least develop upper and lower bounds for the noise of each source, which is often helpful information to have.

Once the source levels for each identified component/mechanism in the product have been determined, the final step in the noise audit process is to compare the sum of the component noise levels to the measured total noise. If the sum and the measured total substantially differ, then the sources have not all been properly accounted for. In practice, the source levels are usually characterized in terms of 1/3 octave band frequency spectra, and there may well be a frequency range where the two do not match, but this range is often where the levels are not high enough to be of concern.

Using the Audit Results to Plan a Noise Reduction Strategy

Once the different sources, paths and noise radiation mechanisms have all been characterized and quantified using the noise audit procedure, they can be rank-ordered based on their contribution to the total noise. This approach then provides a basis for developing an effective noise reduction strategy, starting with the highest level source or sources, so that effort is not wasted on lower-level sources or on a single source that contributes very little to the overall noise level. Such steps permit an organized approach to determining the expected benefits from expenditure of effort and funds. For example, various scenarios can be formulated for achieving a desired overall level of noise reduction, based either on a "balanced design" where the goal is to have all the major sources radiate roughly the same level of noise, or an unbalanced design if it is more feasible to reduce noise from one particular source than another.

The strategies mentioned above assume a goal of reducing the noise by a given amount, expressed in terms of, say, the overall A-weighted sound level. Such a metric does not, of course, always reflect user perception. However, the noise audit procedure opens the door to sound quality evaluations of subjective attributes like "acceptability." Since the sounds of the individual components are now available, they can be altered and mixed together to create the sounds of various "virtual" noise-reduced appliances (reduced according to different scenarios), which can then be presented to a listening panel.

Once the noise audit is complete and a desired noise reduction strategy has been decided upon, then the effort shifts to making modifications and evaluating the resulting noise and performance.

Examples

Figure 1 shows an example of a special test rig that was built to load the motor in a vacuum cleaner so that the noise of the motor itself under representative load could be obtained. This same rig also contained an isolated and quiet motor for driving just the rotating brush so that the noise of that component could also be obtained. ***Figure 2*** illustrates the "window" method being used on another vacuum cleaner, where lead sheet and silencers were used to attenuate all noise sources except the one being measured.

The measured A-weighted source levels obtained by operating various noise sources by themselves in another device are shown in ***Figure 3***. Here, the levels are shown in terms of their A-weighted levels in 1/3 octave frequency bands, with the corresponding overall A-weighted levels shown in the legend. Also included is a comparison that shows the sum of these individually obtained component noise levels are close to the measured baseline level obtained when the entire unit was operating.

Figure 4 shows a schematic of an appliance having an air moving function, with four potential sources of noise. Table I summarizes the noise levels obtained from a noise audit of these individual sources, and presents a "balanced design" strategy for achieving a total reduction of 6 dB. Since this strategy would require a rather severe reduction in structure-borne noise from the motor (achievable, but at a cost of added weight), another strategy is presented in Table II, in which less reduction of the motor structure-borne noise is traded off for slightly more reduction in airborne noise. This illustrates how information from a noise audit can be useful in planning a feasible approach to pursue for achieving a specified noise reduction goal. ■