3pAAb2. Letters from the edge: Less conventional acoustical solutions

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The essence of acoustical analysis and problem solving still is source - path - receiver, yet, as standards, criteria and products evolve, solution precedents should be revalidated or invalidated, and new, innovative approaches should be considered. While weighing the best interests of the client, should one rigidly follow procedures developed long ago for average or anticipated conditions? Or is the conventional wisdom not always correct? This paper presents a noise control product selection procedure and a series of short case-studies where noise or vibration were treated at the source and/or along the path, but with some “twist” or variation from typical solution applications. Relevant standards, ordinances or criteria are referenced. Where available, on-site acoustical measurements, observations or receiver experiences illustrate concepts. A selection procedure for pipe mufflers and duct attenuators is presented. Case studies include industrial engine test cell environmental noise, a coffee roasting and grinding shop within a grocery market and a high-rise domestic water booster/circulation pump room adjacent to a residential unit.

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INTRODUCTION

Noise and vibration design analysis and development of mitigation solutions often begin with identifications of source(s), path(s) and receiver(s). Many common sound isolation, mechanical noise and/or environmental noise intrusion issues have classic solutions or analyses must follow prescribed procedures. Sometimes a novel approach, or at least a variation on the conventional, may lead to a satisfying and effective result. The benefits of the innovation must be balanced against risks to the designer or to the client, particularly if the problem being considered is subject to regulation. One variation on attenuator selection procedure and three noise mitigation case studies, presented below, illustrate small, successful innovations that went beyond conventional approaches.

NOVEL APPROACHES TO COMMON PROBLEMS

Duct Attenuator and Pipe Muffler Selection Process

Pipe and duct noise reduction requirements may necessitate muffler or attenuator insertions. Several selection factors must be considered, including dynamic insertion loss (DIL), static pressure drop (PD), self-generated noise (SN), aerodynamic system effects and dimensional size and physical fit. While the conventional approach may be to obtain at least enough noise reduction to conform to a criterion or noise level limit, my practice has been to first consider neutralization of spectrum, and then secondarily to meet some arbitrarily determined level limit.

Humans perceive tonal noise, even when it is equivalent to or slightly below the broadband continuous ambient level [1]. Therefore, to avoid or reduce noise annoyance due to a particular source, it is beneficial to remove perceptible characteristics of the sound. When that is accomplished, the sound level can be lowered to reduce speech interference, noise intrusion, or whatever relief is needed to achieve the permissible noise criterion.

The process is simple. Determine the spectrum of the source noise, in 1/3 octaves if possible, or even narrowband, but not greater than full octaves. Determine prominent frequencies with the intent to suppress peak frequency amplitude(s). Looking at the typical performance spectra for different designs of mufflers and rectangular duct silencers, one can see that it is possible to select maximum attenuation in almost any octave to match the prominent disturbing frequency of sound, whether from a fan, combustion engine, compressor or other noise source.

Compare sideband levels to determine differentials, e.g., within the 250 Hz octave determine decibel (dB) differences between 200 and 250 Hz 1/3 octaves and between 250 and 315 Hz 1/3 octaves. Do that across the spectrum to locate most prominent tones. Of course, using discretion, one might focus on apparent large differences, and avoid the effort for obviously similar sideband levels. Tonality may be defined as sideband levels greater than 5 or 6 dB [2,3], but for the purpose of neutralizing the source spectrum, select the one or two greatest differentials to be subject to attenuation. Also compare the sound spectrum to permissible noise criteria spectrum, such as A SHRAE Noise Criteria (NC) or Room Criteria (RC) [4] or European Noise Rating Curve (NR) [5], to determine in which octave the undesirable noise exceeds the criteria by the greatest amount.

Consider which prominent frequencies have greater sideband differentials and which most exceed a criterion spectrum to reveal one or perhaps two “critical” frequency bands that need attenuation to reduce perceptible tonality and annoyance. The amount of critical band excess above the criterion is the minimum dynamic insertion loss that should be specified for an attenuator or muffler. Note that this cannot be done with a single number descriptor such as overall A-weighted level (dBA), due to it’s lack of frequency distribution information. Preferably, other non-critical frequency bands should have smaller DILs, in order for the attenuated sound spectrum at the attenuator exit to be less tonal. In other words, if the prominent frequency and it’s immediate sidebands are attenuated equally; the sideband differentials remain unchanged, so that the prominence and the tonality remain in the sound spectrum, therefore attenuation should be greatest at the prominent frequency to reduce it relative to sidebands.

Attenuator size should be determined to minimize face velocity and pressure drop in the duct or pipe. It’s self-noise at design velocity should be checked to assure it does not exceed attenuated sound spectrum. And finally, it should be fit into the duct or pipe layout to without causing system effects, i.e., adequate spacing between the attenuator and any fittings up or downstream to avoid turbulence or friction losses.

Check the full attenuator DIL spectrum noise reduction of the offending source sound spectrum. If any frequency band of the result still exceeds the criteria, reselect the attenuator for greater attenuation, including increase critical band DIL requirement if necessary, to assure the prominent tone neutralization is maintained.
FIGURE 1: Rectangular duct attenuator and various performance spectra (adapted from Industrial Acoustics Co. (IAC) [6].

FIGURE 2: Examples of tubular absorptive (left) and reactive (right) mufflers and various performance spectra [7].

FIGURE 3: Illustration of different attenuation results using attenuators with max insertion loss in different octaves.
Case-Study: Engine Test Cell in Vicinity of Residential Neighborhood

The matching of prominent frequency with maximum attenuation values was used for the exhausts of engine test cells in a suburban area with low exterior ambient sound levels. As presented at Low Frequency Noise Conference, York, UK [8], two major noise sources; the engine exhaust and heated compressed gas were discharged from pipe stacks terminating above the roof. Their noise spectra were different. The engine exhaust, with low frequency dominant sound was fitted with a combination of reactive muffler for low frequency noise and an absorptive muffler for supplemental attenuation of higher frequencies (similar to those illustrated in Fig. 2, above). The hot compressed gas was dominated by higher frequency noise. It was outfitted with a combination of two absorptive mufflers in series, one a straight perforated pipe model and the other an enlarged perforated pipe with inner bullet.

In the following chart, noise spectra of the principal sources are contrasted with results after application of mufflers that had been selected to maximize attenuation at source prominent frequencies. This chart also showed A-weighted spectra to indicate perceptibility to humans. Compared to the tonal source spectra, attenuated exhaust spectra are more flat, with relatively small sideband differentials.

When the two attenuated sources were summed the overall spectrum was similar in shape to the ambient nighttime noise in the neighborhood. The attenuation of test facility noise emissions prevented increase of neighborhood ambient level, resulting in no complaints from the existing neighborhood for the new noise source.

**FIGURE 4**: Source and Attenuated Spectrum Levels at Industrial Engine Test Cell [9]

**FIGURE 5**: Environmental Noise (a) Octave and (b) 1/3 Octave in Neighborhoods With Test Cells Operating and Off [10]
Coffee Roasting and Grinding Shop Noise within a Retail Grocery Market

A coffee grinding and roasting facility was proposed within an upscale retail grocery market in combination with a coffee bar. The owner wished to make roasting and grinding operations visible and audible, but not to permit excessive noise to interfere with speech or annoy shoppers.

Since this is not a sensitive conference, office or presentation/performance facility, a conventional approach to noise control might consider A-weighted overall level, regardless of spectrum. Enough noise containment and/or attenuation could be provided to prevent ambient levels in the store from rising to objectionable levels.

The consultant judged, however, that tonal noise might annoy coffee drinkers at the bar or other shoppers nearby, but more importantly, speech interference from the roasting and grinding operations could increase potential accident or fire threats if workers’ communication were to be compromised. Therefore, acoustical criteria were adopted and design solutions developed to limit noise within the roasting and grinding room, but permit enough noise emissions to be audible in the coffee bar, without increasing levels more than a few decibels over the ambient sound level or interfering with store public address announcements.

Acoustical measurements were conducted at the coffee roaster operator’s existing prototype facility, using identical roasting and grinding equipment as that proposed for the grocery store. Individual steps of the roasting process were measured in short duration 1/3 octave equivalent levels (Leq) approximately 3’-6’ (1-2 m) from the equipment. In addition, statistical or percentile (Ln) levels were measured across a complete roasting cycle, from filling the raw beans to starting the combustion to emptying the roaster and cooling the beans. The statistical spectra indicated which frequencies in the roasting room were dominant and how much the levels varied during the roasting cycle. One could also determine how much of the time levels could prevent good vocal communications. Outdoor measurements were also conducted to determine exhaust and combustion flue noise emissions.

Table 1: Summary of Airborne Equivalent Sound Levels (Leq) [11]

<table>
<thead>
<tr>
<th>Sound Source</th>
<th>A-Wtd Leq</th>
<th>C-Wtd Leq</th>
<th>Peak Octave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete roast cycle (12 min avg)</td>
<td>88.8</td>
<td>93.0</td>
<td>250 Hz</td>
</tr>
<tr>
<td>Load roaster (pour beans)</td>
<td>80.2</td>
<td>78.6</td>
<td>4-8 kHz</td>
</tr>
<tr>
<td>Start-up burner (pre-heat)</td>
<td>95.1</td>
<td>99.0</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Roast Process</td>
<td>89.6</td>
<td>93.3</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Secondary cooling (fan)</td>
<td>77.1</td>
<td>85.2</td>
<td>250 Hz</td>
</tr>
<tr>
<td>De-stoner (fan &amp; beans)</td>
<td>96.6</td>
<td>99.2</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Exterior fan-cyclone exhaust</td>
<td>64.4</td>
<td>75.1</td>
<td>125 Hz</td>
</tr>
<tr>
<td>Exterior room prop-fan exhaust hood</td>
<td>77.5</td>
<td>81.6</td>
<td>250 Hz</td>
</tr>
</tbody>
</table>

The roasting room and the immediately adjacent coffee bar acoustic designs were developed based on the prototype system measurement results, with levels modified slightly to account for a smaller planned roasting room at the store. Exhaust and flue levels were also considered in regard to potential environmental noise disturbance to other nearby properties, but determined not to significantly exceed the outdoor or environmental noise levels at the retail facility. The architectural design recommendations [12] incorporated the steps listed below.

1. Roasting room partition designs of framed drywall with large view windows. Resilient mountings were recommended for drywall. Sheet metal heat shields were to be applied to lower partitions near roasting equipment. Laminated glass was recommended for better noise containment at glass coincidence frequencies. Provide edge seals for double-swing impact door.

2. Acoustically absorptive ceiling plus some absorption on non-glazed wall surfaces were recommended to limit reverberant noise build-up within the roasting room.

3. Partition and ceiling penetration seals were recommended for pipes, conduits and ventilation ducts to prevent flanking sound. Duct lagging was considered, but a large walled-in ceiling plenum above the roasting room was extended to the roof deck above for visual reasons. It was adequate to contain duct and flue pipe radiated noise.

4. Attenuators were recommended for the combustion blower discharge (maximum dynamic insertion loss in 250 Hz octave to match peak noise and for duct exhaust inlet).

5. Vibration isolation mountings were recommended for combustion blower, roaster and exhaust fan to reduce transmission via floor to nearby partitions that could re-radiate airborne noise. In addition, louder-noise equipment should be located at least 6”-12” (150-300 mm) from walls to avoid “driving” or exciting partitions via acoustic coupling.
Each of the acoustical recommendations were eventually accepted and implemented, except for the combustion blower attenuator. Estimated noise at the Coffee Bar and on grocery sales floor, based on implemented recommendations, versus previously measured grocery store ambient spectrum level is shown in Fig. 7 (b) [13].
Pump Noise and Vibration in High-Rise Residential Facility

Domestic hot water risers in a high-rise residential building required booster pumps on each 8th floor to equalize water pressure throughout the building. The 1.5 – 2 horsepower pumps had not been considered a mechanical noise issue in design. They were enclosed in mechanical closets along corridors and located adjacent to residential kitchens and laundry closets. Nevertheless, audible hums were reported in unoccupied units available for sale. The acoustical consultant was called in to investigate and recommend remediation.

![Figure 8: Pump Closet Plan and View of In-line Pump Installation]

The conventional approach might be to reduce airborne sound transmissions of motor noise, add absorption to the pump closed to reduce reverberant build-up, re-seal partition penetrations, add mass to the partition, etc., so that audible sound in receiving room was less perceptible.

The consultant visited the site. Mechanical noise was audible in the corridor near the pump closet. Acoustical measurements indicated the pump motor noise was not greater than expected for a properly functioning pump and motor. The partitions appeared to be constructed per design with adequate penetration seals. Inside the adjacent residential unit, however, the pump was still audible. By pressing an ear against the kitchen cabinets, noise from structure borne vibration was apparent. Vibration isolation was found to be the key solution in lieu of airborne noise control.

Airborne noise reduction was recommended, primarily to prevent residential residents from hearing the pump noise in the public corridor and “cueing” them to listen for it in their units:
1. Acoustical door seals to reduce transmission into public corridor.
2. Room absorption to reduce reverberant build-up of sound.
3. TEFC motor mute to reduce motor noise radiation from vent inlet.

Vibration isolation was specified within the pump room to reduce structure borne transmission to the immediately adjacent residential unit, including:
1. Break an existing cement grout pump base mounting and insert vibration isolation pads to reduce vibration transmission into floor structure
2. Insert vibration isolation pads in existing pipe hangers to reduce vibration transmission into structural slab above.

With the steps above completed, the construction manager and condominium manager determined subjectively that corridor and residential unit noise was reduced enough to meet perceived occupant expectations. The pump motor inlet attenuator, therefore, was not installed [15].
CONCLUSIONS

Novel or prototypical solutions to noise and vibration control may be found, but the classic search for “source – path – receiver” relationship remains integral to successful acoustical design or remediation of noise issues.

REFERENCES

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9 Ibid. "Engine Test Cell Noise"
10 Ibid. "Engine Test Cell Noise"
12 Ibid. “On-Site Airborne Sound and Floor Vibration Measurement Results”
15 Ibid. “In-Line Recirculation Pumps”