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ENVIRONMENTAL NOISE

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Abstract

This paper provides an overview of the various environmental noise regulations applicable to the IAGT community, with examples from jurisdictions that maintain more detailed and prescriptive ordinances. Key aspects are highlighted, including applicable environmental approval processes, equipment/facility design considerations, examples of types of engineered noise control measures and the potential consequences of failing to adequately address environmental noise emissions from industrial gas turbine applications.

Introduction

As industries and communities evolve and expand, they inevitably encroach upon one another, creating potential compatibility concerns, not the least of which is environmental noise. Industrial gas turbine applications are certainly no exception; in fact, some applications such as natural gas storage and transmission can be nestled directly within residential neighbourhoods by necessity of being close to the market. In order for such installations to operate harmoniously within their communities, industrial gas turbine operators must be aware of, and ensure they are complying with, all applicable environmental noise regulations which may exist at all three levels of government. To be successful, operators must also work closely with their facility designers and equipment suppliers to ensure that regulatory obligations with respect to noise are a priority at the design stage, such that amicable relationships with surrounding communities are maintained.

A variety of specialized terms is used throughout this paper, a glossary of which is included following the "Closing Remarks" section.

The Importance of Environmental Noise

The simplest definition of noise is "unwanted sound". In the context of environmental noise from industrial facilities, unwanted sound can adversely affect community members in a number of ways. It can interfere with people's ability to enjoy their property. Unwanted sound can also interfere with restful sleep. If sufficiently disturbing, environmental noise can lead to complaints, either to the emitter of the noise, or to one or more levels of governing authority. It is this community response to noise that led to the development and enforcement of regulations/ordinances, etc., at various levels of government in most jurisdictions. It is important for operators of industrial facilities, particularly those that include gas turbine installations, to be aware of and ensure these legal obligations are being respected.

In some cases, there are federal regulations (or guidelines) on environmental noise; more common, however, are state/provincial or county/municipal level regulations, which apply under varying circumstances, and are enforced to varying degrees. For instance, in some jurisdictions such as Ontario, Canada, the provincial government must grant an environmental approval before a new plant can be constructed; applying for such approval includes demonstrating, through technical study, that the sound levels of the plant will comply with Provincial guidelines. Similarly, many jurisdictions require Environmental Assessments (also referred to as Environmental Impact Assessments, Environmental Impact Statements, among other terms) be completed prior to the granting of government approvals of major projects. In other cases, adherence to environmental noise standards can be a condition of financing from organizations such as the World Bank.

Beyond legal or financing obligations driving environmental noise compliance, many leading industries maintain policies on corporate social responsibility, which promote accountability in several key areas, typically including environmental protection and the wellbeing of the community in which they operate or serve. Adherence to such policies can be the impetus for the proactive reduction of environmental noise emissions, rather than reactively addressing noise complaints as they occur.

Types of Environmental Noise Limits

The environmental noise limits that might apply to a gas turbine installation vary widely from one jurisdiction to the next. In many cases, interpreting noise regulations/ordinances as well as determining whether the sound levels of a plant comply with any applicable limits warrants the assistance of an acoustical consultant. Nevertheless, the following are several aspects of noise regulations/ordinances that provide some insight into the sorts of limits that might apply to your plant:

1. Where the evaluation is conducted – that is, the noise limit can apply at any of several possible locations. Limits can be a “point of emission” criterion, governing the noise output of a source, regardless of where a listener may be. They can also apply at the property line of the industrial facility. In most cases, though, the limits are “point of reception” criteria, which apply at a neighbouring noise-sensitive property, such as a residence, hospital, school, or place of worship.

2. Qualitative versus quantitative criteria for evaluation – Limits for environmental noise can be qualitative, quantitative, or sometimes both. A qualitative limit is based on a judgement or decision by an enforcement official (e.g. a noise control officer) usually regarding whether the sound is loud enough to be “likely to disturb”, without reference to any numeric sound levels. For instance, a “plainly audible” noise could be a violation of a subjective limit that prohibits such a condition. A quantitative approach assesses a measured sound level against a maximum permitted level stipulated in a regulation or ordinance. Quantitative limits have the advantage of removing bias (from an enforcement official), but are not without their complications, as discussed further below.

3. Fixed versus relative limits – When it comes to quantitative criteria, they can be implemented in two ways (and sometimes both). One is a fixed limit that may not be exceeded (e.g. 50 dBA at a given location). The other is a relative limit that takes into consideration the presence of background sound from other sources (such as road traffic and/or natural sounds). Typically, the limit stipulates a maximum allowable increase over the existing background sound. A combination of the two involves a relative limit that is applicable in cases where appreciable and steady background

sound is present, and a fixed "exclusionary limit" in cases where the background sound is low (the World Bank limits [1] are of this form).

4. Limits by type of activity, date or time – In some cases, certain activities are prohibited, either altogether, or by date and/or time. For example, prohibition of loading and unloading of materials during nighttime hours, and on Sundays.

While environmental noise limits, particularly quantitative ones, are generally based on sociological research studies of community response to noise, the differences in limits among different jurisdictions arise from the fact that interpretation of the research and experience-based judgement are needed in choosing a limit that best reflects the probability of noise impact or adverse community response. With that said, it is worth noting that complying with an applicable noise regulation/ordinance does not preclude the possibility of noise complaints, which may warrant the adoption of more stringent sound level targets, for risk-management reasons, as discussed in the following section.

Examples of Regulatory Frameworks and Limits for Noise

The following subsections are intended to provide a brief overview of a number of regulatory frameworks and limits for noise in Canada, the United States and Europe that may be applicable or of interest to industrial gas turbine operators. These overviews are not comprehensive summaries of the various regulations and ordinances; readers are encouraged to review any regulations/ordinances of particular interest in their entirety, to ensure all aspects are understood.

Ontario Ministry of the Environment and Climate Change ("MOECC")

The Provincial noise guidelines in Ontario, Canada, are perhaps the most comprehensive and restrictive in North America. Section 9 of the Ontario Environmental Protection Act [2] requires that the MOECC grant an Environmental Compliance Approval ("ECA") before the construction or operation of any new equipment or facility that emits contaminants to the environment (including noise). Applying for an ECA includes demonstrating that the sound levels of the plant will comply with the limits stipulated in MOECC Guideline NPC-300 [3], through the preparation of an Acoustic Assessment Report ("AAR"). In the case of existing equipment/facilities for which an ECA has not previously been issued, sound emissions therefrom must be shown to meet the applicable limits; if not, then a Noise Abatement Action Plan is required, which details the proposed noise control measures and implementation timeframe thereof in order to achieve the applicable limits. Any such abatement plan cannot be implemented until approved by the MOECC.

The sound level limits in NPC-300 apply on the premises of a noise-sensitive point of reception, such as a residence, hospital, school, or place of worship, which includes any vacant lands with a Municipal zoning designation that permits a noise-sensitive use (e.g. agriculturally zoned lands on which a dwelling is permitted). The limits are quantitative, and site dependent, based on the existing ambient background sound levels in the area. In essence, the sound from the facility of interest is evaluated against (i.e. compared to) the characteristic background sound at any potentially impacted points of reception. Specifically, NPC-300 stipulates a sound level limit that is the greater of the minimum one-hour energy-equivalent (L_{EQ}) background sound level, or the following exclusionary minimum limits:

Table 1: MOECC NPC-300 Exclusionary Minimum Sound Level Limits, L_{EQ} [dBA]

Acoustic Environment	Daytime (07:00 to 19:00)	Evening (19:00 to 23:00)	Nighttime (23:00 to 07:00)
Urban	50	50	45
Rural	45	40	40

NPC-300 also stipulates that the noise assessment shall consider a predictable worst-case hour, which is defined as an hour when typically busy operation of the facility under consideration could coincide with an hour of low background sound.

The MOECC guidelines include adjustments for time-varying sound, various penalties for sounds of distinct audible character (such as “tonal” sound) as well as specific limits for impulsive sound. In general, noise arising from emergency situations, as well as most construction activity is exempt from these limits.

Alberta Energy Regulator

Alberta, Canada, also enforces comprehensive noise limits, particularly applicable to the energy industry. Established by the Responsible Energy Development Act [4], the Alberta Energy Regulator (“AER”) maintains and enforces various regulations and directives, including Directive 038: Noise Control [5], which is applicable to facilities related to oil and gas production, storage and transportation, coal mining and electrical generation facilities. Any such facility is required to comply with Directive 038, with the exception of those constructed and in operation before October 1988; such “deferred facilities” needn’t demonstrate compliance in the absence of a complaint. However, the AER intends to eliminate the deferred status for pre-1988 facilities as of October 17, 2018.

When applying to the AER for approval of a new facility or expansion of an existing one, a Noise Impact Assessment (“NIA”) must be completed to demonstrate that the facility will meet the limits applicable in Directive 038. If the NIA indicates noncompliance, the applicant must consider further attenuation measures; existing, non-compliant facilities must comply with any noise control implementation timeframe proposed to and/or imposed by the AER. If compliance is deemed not practical, the applicant must provide the AER with details regarding why complying with the Directive is not practical.

The noise limits in Directive 038 apply at any dwelling impacted by a given facility; if there are no dwellings in the vicinity, then facility sound levels must meet 40 dBA (L_{EQ}) at 1.5 kilometres from the facility fence line. At any dwelling, the Permissible Sound Level (“PSL”) is calculated as follows:

$$\text{Permissible Sound Level} = \text{Basic Sound Level} + \text{Daytime Adjustment} + \text{Class A Adjustment} + \text{Class B Adjustment}$$

Where,

The Basic Sound Level (“BSL”), ranging from 40 to 56 dBA, is considered to apply during nighttime hours (22:00 to 07:00), and is dependent upon proximity of the dwelling to major road/rail/air transportation corridors and the local population density;

The Daytime Adjustment of 10 dBA (L_{EQ}) above the nighttime criteria applies to facilities/equipment/activities that operate during daytime hours only (07:00 to 22:00);

The Class A Adjustment is based on the seasonality of a facility (a +5 dBA adjustment is applicable to wintertime only operation, and only in the event of a complaint investigation; this adjustment is not to be applied when determining the PSL for design purposes) and the ambient sound level ("ASL"). The ASL is the average sound environment in a given area without the contribution of any energy-related industry; an adjustment of -10 to +10 dBA can be applicable only when the BSL is thought not to be representative of the actual sound environment and when ASLs have been measured.

The Class B Adjustment addresses temporary activities, with adjustments of +5/+10/+15, respectively, for activities occurring for <60 days/7 days/1 day.

For an NIA, the predicted facility sound level is logarithmically added to the average rural ASL (5 dBA less than the BSL), and the combined facility and ambient noise level is compared to the PSL. In the case of investigating a noise complaint, the actual isolated facility sound levels are compared to the PSL.

Like the Ontario guidelines, the AER exempts noise arising from emergency situations and most construction activities. Although there are no specific limits for impulsive sounds, Directive 038 includes a specific procedure for assessing low frequency noise (defined therein as sound below 250 Hz).

United States

While there are a number federal regulations applicable to environmental noise in the United States ("US"), the majority of noise protection policy is maintained at state or local (county or city) levels, based on the general strategy set out in the Framework for Community-Based Environmental Protection [6], issued by the Environmental Protection Agency ("EPA"). However, some federal agencies such as the Federal Energy Regulatory Commission stipulate a sound level limit of 55 dBA in Noise Sensitive Areas (i.e. residential areas), for some industrial installations such as compressor facilities (which commonly employ gas turbine engines). The following subsections provide brief examples of State and City noise ordinances in the US.

State of New Jersey

The New Jersey Administrative Code, Section 7:29 [7], specifies sound level limits for industrial facilities, in terms of the maximum sound pressure level at a neighboring property line. The limits differ slightly depending on whether the neighboring property hosts a residential use versus a commercial/community service use. The applicable limits are listed in Tables 2 and 3, below, notably applicable to both A-weighted sound levels, and to individual octave band sound levels:

Table 2: New Jersey Limits for Sound Levels at a Residential Property Resulting from an Industrial, Commercial or Community Service Facility [dB re 2 x 10-5 Pa]

Time Period	Octave Band Centre Frequency [Hz]									dBA
	31.5	63	125	250	500	1k	2k	4k	8k	
07:00 to 22:00	96	82	74	67	63	60	57	55	53	65
22:00 to 07:00	86	71	61	53	48	45	42	40	38	50

The code states that the limits in Table 2, above, apply to both non-impulse sounds, and impulse sounds that could occur more than four times per hour.

Table 3: New Jersey Limits for Sound Levels at a Commercial/Community Service Property Resulting from an Industrial, Commercial or Community Service Facility [dB re 2 x 10-5 Pa]

Octave Band Centre Frequency [Hz]									dBA
31.5	63	125	250	500	1k	2k	4k	8k	
96	82	74	67	63	60	57	55	53	65

The code also includes an impulsive sound level limit of 80 dBAI at the property line of a commercial/community service property.

City of Norcross, Georgia

The Norcross Municipal Code, Section 26, Article II, "Noise Control" [8], provides a blanket prohibition of excessive noise ("which unreasonably interferes with the comfort and repose of others within the jurisdiction of the city") as well as maximum permissible sound levels. The sound level limits are "point of reception" criteria, in that they specify the maximum sound level that can be produced by a source at or beyond the property line of a neighboring property. The limits vary depending on the land use category of the property where the sound is received.

Table 4: City of Norcross, Georgia Sound Level Limits, [dBA]

Land Use Category	Point of Reception	Maximum Permissible Sound Level	
		07:00 to 22:00	22:00 to 07:00
Residential, noise-sensitive area, public space	Outdoors	70	65
Multifamily dwelling	Indoors	65	60
Commercial	Outdoors	75	70
Industrial	Outdoors	85	

State of Pennsylvania: Noise Considerations for "Unconventional Wells"

The Pennsylvania Department of Environmental Protection ("DEP") recently proposed changes to environmental regulation of "unconventional wells" [9] (which include oil and gas wells that commonly employ gas turbine powered compressors), including environmental noise emissions. Under the proposed regulation, well operators would be required to develop a noise mitigation plan to "minimize noise during drilling, stimulation and servicing activities", which would include a background noise assessment, an assessment of the potential noise from drilling activities at nearby residents, and a noise mitigation plan. The proposed language included no quantitative limits for noise, nor any guidance on what constitutes acceptable noise levels, which has led to widespread criticism by industry groups, on grounds of ambiguity and lack of enforceability. The Pennsylvania Independent Oil and Gas Association opined that the new and expanded provisions in the final draft "will significantly burden" both the conventional and unconventional oil and gas industry in Pennsylvania "to the point of stagnation" [10] Citing the "complex nature" of technical issues involving noise mitigation, the DEP elected, instead, to publish a set of best practices for managing noise and consider creating a rule in the future. [11]

Europe

In Europe, there are what could be considered two different "streams" of environmental noise management: an over-arching policy framework at the European Union level called the

Environmental Noise Directive ("END") [12], and the unique noise regulations of each nation, region or City (although the latter tends to be addressed through "nuisance" by-laws, which are generally subjective and enforced primarily in response to individual noise complaints).

The END defines the basic principles of a harmonized European noise policy and requires each member nation to assess environmental noise from major sources such as industry and transportation, as well as to quantify how many people are exposed to various noise levels. With the areas of greatest noise impact identified, action plans are required that aim to reduce noise exposure in those areas. Under the END, member states are required to prepare and publish, every 5 years, noise maps and noise management action plans for cities with populations greater than 100,000 people, as well as for major roads, railways and airports. The process is intended to be iterative, continuously addressing areas where environmental noise impacts are greatest.

Denmark

Denmark is one of a myriad of European Union nations that federally regulates environmental noise. The Danish Environmental Protection Agency maintains limits for noise in Guideline No. 5/1984, "Outdoor noise emission from industrial sites" [13]. Those limits apply in eight types of areas, depending on the day of the week and time, as summarized in the following table:

Table 5: Danish Environmental Protection Agency Sound Level Limits, L_{EQ} [dBA]

Area Type (Usage)	Time Periods		
	Mon - Fri 07:00 to 18:00 Sat. 07:00 to 14:00	Mon - Fri 18:00 to 22:00 Sat. 14:00 to 22:00 Sun. 07:00 to 22:00	All week 22:00 to 07:00
Industrial area	70	70	70
Business and industry area with restrictions	60	60	60
Areas with mixed residences and businesses, city centre	55	45	40
Multi storey dwellings	50	45	40
Areas for open and low residential dwellings	45	40	35
Summer house, public recreational and special natural areas	40	35	35

Note: Special limits for allotment gardens and open country have been excluded, for brevity.

Guideline No. 5/1984 also includes adjustments to the applicable sound level limit for time-varying sources, and a 5 dB annoyance penalty for noise that "contains either clearly audible tones or clearly audible impulses". In addition, the guideline includes explicit consideration of low frequency noise (defined in the guideline as A-weighted sound between 10 and 160 Hz) and infrasound (defined in the guideline as G-weighted sound between 5 and 20 Hz).

Acoustical Design Considerations

Noise from a completely new facility could obviously result in a significant “wake up call” to the surrounding community, particularly a new gas turbine installation in a relatively quiet rural area. For the expansion of an existing plant, such modifications can increase the overall sound levels in the community (or change the character of the sound that neighbours hear), which can also be of concern. In either case, the first step in addressing any potential concerns with regard to environmental noise is to identify and understand any legal obligations. Complying with any applicable sound level limits should be the first priority. The overview provided in the previous section serves to demonstrate the wide range and complexity of regulatory frameworks and limits for noise that are applicable in various jurisdictions. Nevertheless, if there are no noise regulations/ordinances applicable in a given jurisdiction, it may still be prudent to consider those of a nearby or similar locale. In the case of expanding an existing facility, it may be sensible to design the expansion such that plant-total sound levels do not increase appreciably in the surrounding community. The absence of a noise regulation/ordinance does not absolve an operator of its corporate/social responsibility to protect the wellbeing of their community.

Once targets for community noise levels have been identified and/or selected, the sound levels of a proposed new or expanded facility can be predicted using a computational acoustical model (note that AER Directive 038 stipulates specific requirements for sound level prediction methodology). Such 3-dimensional models can be populated with local topography, onsite and offsite structures (which afford acoustical shielding and reflections), and information regarding significant noise sources based on manufacturer’s data (where available), predictions using generic data from reference texts, or on measurements of similar equipment. Note that, for important efforts such as this, leading suppliers of components of industrial gas turbine installations can expect acoustical data to be more frequently requested; to that end, having accurate acoustical data available can represent a competitive advantage. With a complete acoustical model of the site and surrounding area, the predicted sound levels of a proposed new or expanded facility can then be evaluated with respect to target levels; if noise control measures are found to be warranted, they can be efficiently designed to suit (see the following section for examples of engineered noise control measures).

An acoustical design consideration of particular note in the context of industrial gas turbine engines is that of the tonal “whine” that is generated at one or more of the blade pass frequencies of the gas turbine, or associated gas compressor (if applicable). The previous section on noise limits gave several examples of ordinances that include an often severe penalty for noise with a tonal character, given the increased likelihood of disturbance. Therefore, careful consideration must be given when designing industrial gas turbine installations in order to minimize the amount of audibly tonal sound that is emitted to the environment.

Gas turbines are commonly employed at gas compression facilities, which are often found in relatively rural areas where noise limits can be restrictive, and background sound levels low (thereby increasing the audibility of such a facility at greater distances). While noise from the turbine/compressor casings as well as ventilation and combustion air intakes/exhausts are generally straightforward to address, noise emitted from above-grade piping can be a particular challenge, particularly piping directly leading to/from the gas compressor. As noted in the previous paragraph, gas compressors typically produce a blade pass frequency tone, which is transmitted through the gas medium in the piping, and radiated to the environment through the piping walls. The use of acoustical enclosures can be prohibitively expensive for sites with extensive amounts of large diameter above grade piping (and associated valves/scrubbers), and there are practical limitations to the amount of attenuation that can be achieved through the application of acoustical lagging (insulation). Some facilities have employed “acoustic arrays” within the piping itself – these are effectively resonators tuned to absorb sound at one or more narrow frequency bands (i.e. the blade pass frequency), which can be effective for steady-state operations. However, for applications where the gas compressor is operated at varying speeds, the effectiveness of such measures can be quite diminished.

The nature of some industrial gas turbine operations are such that they include occasional or frequent “blowdown” events, which involve the release of high pressure gas to the atmosphere that can also be accompanied by significant noise emissions (if not adequately controlled). Such noise emissions are generally subject to the same regulations and ordinances (if applicable) as would any other industrial noise, although the resultant sound level may be “time weighted” if the duration of the blowdown event is less than the averaging time of the applicable quantitative sound level limit (e.g. 1-hr L_{EQ}). Given the occasional nature of such events and the typically high sound levels associated therewith, the potential for blowdowns to be disturbing to neighbouring residents is greater, relative to steady operation of a gas turbine (which typically results in lower, and consistent environmental sound levels). Moreover, blowdowns can affect the health and safety of workers who may be in the area. Therefore, the inclusion of blowdown silencers is an important design consideration for any new or expanded gas turbine installation.

Types of Engineered Noise Control Measures

Silencers

A silencer is a device which allows flow-through of air or other gases but which removes some portion of the acoustic energy from the gas flow which passes through it. Commonly, silencers can be installed on ventilation inlet or outlet openings, in ducts, at the discharge of exhaust stacks, or on the combustion discharge of engines. Dissipative silencers utilize internal baffles that are parallel to the flow, with perforated facings and acoustically absorptive fill, such as fiberglass or mineral wool. Reactive silencers, sometimes called mufflers, consist of an interconnecting series of tuned internal cavities and tubes, etc., which use resonance and anti-resonance to attenuate the sound passing downstream. Each of these silencers will introduce an additional backpressure to the flow path, and generally the incremental backpressure increases with increasing noise reduction. The backpressure can be minimized by using silencers with greater cross-sectional dimensions and/or length. So, when selecting a silencer, the required acoustical performance must be

Figure 1: An industrial gas turbine exhaust silencer.

balanced against the allowable additional backpressure and space constraints. The allowable backpressure will be determined by the device driving the gas flow, such as a fan, an engine discharge or natural convection. It is also important to take into account the temperature of the gas stream, because the acoustical performance of all silencers is affected by temperature, and most catalog data is cited at just one temperature (such as room temperature). Another key consideration is whether the gas stream contains any corrosive compounds, particulate or other materials that could clog the porous absorptive media or cause deterioration of the silencer materials. The acoustical performance of silencers is usually specified in terms of dynamic sound insertion loss (“IL” or “DIL”) in each octave frequency band, which represents the difference in sound level downstream of the silencer, with and without the silencer in place. (“Dynamic” refers to the performance at design flow rate, versus its performance without flow, which may differ slightly.)

Acoustical Enclosures

The concept of an acoustical enclosure is simple – it is an enveloping structure that contains and then dissipates the sound emitted from a source. To be effective, an acoustical enclosure must fully envelope the source, with no open gaps or cracks. In most cases, ingress and egress openings are necessary, either for ventilation/cooling air or to allow materials to pass in and out of the enclosure as part of a production process. Such openings generally must be fitted with silencers or lined acoustical passages, because even very small untreated openings or gaps in the enclosure can significantly or entirely degrade its acoustical performance. The acoustical performance of an enclosure depends on the weight and composition of the wall/roof assembly, the degree to which it can be physically decoupled from the source to avoid vibratory transmission of acoustic energy, its size relative to the source, and the amount of acoustic absorption present inside the enclosure. The acoustical performance of an enclosure is best specified in terms of sound insertion loss (“IL”) in each octave frequency band, which represents the difference in sound level outside the enclosure, with and without the enclosure in place.

Noise Barriers

A noise barrier is similar in some ways to an acoustical enclosure, but it does not fully envelope the source. It can be a single noise wall, or a multi-sided barrier that surrounds a source on two, three or four sides. A noise barrier is effective to the extent that it casts an “acoustical shadow” between the source and the point of reception. That is, if a barrier does not break the imaginary straight line connecting the source and the receiver, it has no acoustical effect at that receiver. To the degree that the height and width of the barrier extend beyond the straight line connecting the source and receiver, the acoustical performance of the barrier is greater. However, because a noise barrier does not fully enclose the source, its acoustical performance is always limited by “diffraction”, which is the tendency of sound to bend over or around the edges of the barrier. Because of diffraction, the theoretical maximum noise reduction possible with a barrier is 20 to 25 decibels, but in most practical situations, the maximum reduction possible with a barrier is 10 to 15 decibels. While the geometry of the barrier (its height, width, and placement relative to the source and receiver) is the primary factor determining its performance, it is also important that the material from which it is constructed be solid, durable, air-tight, and free of gaps and cracks within and below its full extent. Also, to be effective, the barrier material must have sufficient mass; in general, a minimum surface density of 20 kg/m^2 (4 lb/ft^2) is sufficient, which can be reduced in certain cases, if justified via an engineering acoustical analysis. It is important to note that reflected sound from solid surfaces near the barrier or from the barrier itself can degrade its acoustical performance. Therefore, it is important to assess whether acoustically absorptive treatments are necessary for the surface of the barrier, or other solid surfaces in the vicinity. Because the acoustical performance of a barrier varies significantly at different positions around the barrier and depending on the geometry of the environment in which it is placed, it is not practical to specify a barrier in terms of its sound insertion loss. Instead, barriers are typically specified by citing physical dimensions and material properties, determined through an engineering acoustical analysis.

Acoustical Lagging

Some vibrating surfaces that emit sound, such as piping, a vessel, or a machine housing, can be treated with acoustical "lagging" (wrapping). Like an acoustical enclosure, the function of lagging is to contain and dissipate a portion of the sound. However, because lagging makes full-surface contact with the vibrating source, its acoustical performance is limited in certain respects. Most important is that acoustical lagging actually increases the radiated sound at low frequencies, relative to the unlagged case. This effective amplification occurs because of certain unavoidable resonances that occur between the outer surface of the lagging and the vibrating surface within and, in the case of piping, because of the increase in external radiating surface area, resulting from the application of the lagging. Different lagging assemblies amplify to different degrees and in slightly different low frequency ranges, but generally the increase in radiated sound can range from 5 to 10 decibels in the 63 to 400 Hz range. For this reason, acoustical lagging is an effective noise control measure only when the noise of concern is concentrated in the mid and high frequency range, greater than 500 Hz. If the source of concern emits no significant sound below 500 Hz, then acoustical lagging can provide 10 to 40 decibels of reduction, depending on the assembly used. Lagging generally consists of one or more limp, massive barrier layers, separated from the noise-emitting surface by one or more layers of fibrous or porous acoustically absorptive decoupling layers (typically mineral wool or fiberglass), usually with a protective outer jacket. It is important to note that some insulation materials used for thermal lagging have poor or negligible acoustical performance, including any non-porous or closed-cell materials. In general, lagging assemblies with thicker absorptive layers and heavier limp barrier layers provide greater noise reduction. Ancillary concerns about heat accumulation, access and effects on corrosion should be taken into account when contemplating the use of acoustical lagging as a noise control measure. Acoustical lagging can either be specified in terms of its sound insertion loss ("IL") in each octave frequency band, which represents the difference in sound level radiated from the surface, with and without the lagging in place, or by describing the lagging assembly in terms of its physical and material parameters.

Figure 2: Acoustical lagging on 1 metre diameter suction piping (and scrubber) of a gas turbine-powered natural gas compressor plant.

Consequences of Failing to Address Environmental Noise

Environmental noise is regulated at some level of government in nearly all locales in the developed world, whether it be in the form of quantitative limits (several examples of which are discussed above), or qualitative limits (e.g. limiting any sound that is loud enough to be “likely to disturb”). Such regulations/ordinances are generally accompanied with clear consequences which, for industrial operations could take the form of fines, legal orders to implement noise control measures or, in extreme cases, legal orders to suspend operations. However, such ominous and tangible consequences should not be allowed to overshadow the importance of industrial facilities protecting the wellbeing of and existing harmoniously within the communities in which they operate or serve (whether encoded in a corporate social responsibility policy, or not).

Closing Remarks

This paper only scratches the surface of the immense topic of environmental noise, providing simplified examples of what are complex regulatory frameworks and limits for noise. The challenges faced by operators of industrial gas turbines in complying with such regulations/ordinances can be considerable, particularly when such facilities are located next to or even within residential communities. As concern regarding noise continues to grow in both our biggest cities and our most rural areas, operators of industrial gas turbines, and industrial operators in general, will be well served to ensure that they continue to stay well informed and meet their legal and social obligations regarding noise.

Glossary

Sound Pressure Level

The human ear perceives oscillations in air pressure as sound. The magnitude of the oscillations determines the loudness of the sound, and is typically measured logarithmically, in terms of sound pressure level, in units of decibels [dB]. A faint whisper might produce only a few decibels, while a loud shout can exceed 100 dB at close range. As a rule of thumb, an increase or decrease of 10 dB in sound level is perceived as a doubling or halving of the loudness, approximately. Likewise, an increase/decrease of 5 dB in sound level equates to a perceived change of about 25% in loudness, and an increase/decrease of less than about 3 dB is typically considered imperceptible. A negative sound level is not taking away acoustical energy from the environment, but is below the threshold of perceptibility. In the context of outdoor sound propagation, attenuation is a result of several factors, the most significant of which is *geometric spreading*. The sound level of a simple point source (which radiates sound equally in all directions) is reduced by 6 dB for each doubling of distance from the source; for a line source (such as a length of piping, or a highway), the sound level is reduced by 3 dB for each doubling of distance from the source.

Pitch and Frequency

In addition to differences in magnitude, the human ear perceives differences in the frequency or “pitch”, of sounds, which corresponds to the number of pressure oscillations occurring per second, measured in units of Hertz [Hz]. 1 Hz is equal to 1 oscillation per second. A low frequency sound (in the “bass” range), such as a tuba or rolling thunder, exhibits a relatively small number of oscillations per second, while a high frequency sound (in the “treble” range), such as a piccolo or a hissing air leak, consists of thousands of oscillations per second. The audible frequency range for human hearing extends from about 20 Hz to 20 kHz (20 kHz = 20,000 Hz).

A-weighting and Octave Bands

Most sounds can contain a mixture of many frequencies simultaneously. The human ear varies in its sensitivity to sounds of different frequency. Therefore, sound levels are often measured using a frequency-weighted filter which emulates the frequency sensitivity of the human ear. The frequency-weighting is referred to as the “A-scale.” Most instrumentation for measuring sound has the capability to weight all of the component frequencies of a sound, and sum them into a single, “spectral-sum” number; sounds measured in this way are designated in units of A-weighted decibels [dBA]. A dBA spectral-sum sound pressure level is a reasonable single-number representation of the perceived overall loudness of a complex sound that contains multiple different frequencies.

For the more detailed purposes of analyzing outdoor propagation of sound over a distance, the single-number A-weighted sound level is insufficient, because the factors that attenuate sound as it disperses affect different frequencies of sound in very different ways. In this context, the audible frequency spectrum is typically divided into a series of “bands” with a frequency width of one octave (or sometimes 1/3 octave) instead of aggregating all of the frequencies into a single-number, A-weighted sum. A sound level measurement conducted in this manner comprises a set of separate decibel values, with the level in each frequency band quantified by one corresponding decibel value. Most commonly a “spectral” measurement of this sort is conducted in eight octave bands, with centre frequencies ranging from 63 Hz to 8 kHz. When very low frequency sound is also a concern, the spectrum might include the level in the 31 Hz octave band.

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