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NOISE ATTENUATION OF NATURAL GAS COMPRESSORS USING ACOUSTIC ARRAY TECHNOLOGY

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Abstract

This paper provides an overview of environmental noise considerations in the context of a natural gas compression facility, the noise control measures traditionally employed to control noise at such facilities, and of acoustic array technologies. An acoustic array is introduced at the gas compressor diffuser, downstream of the impeller exit. Employing multiple noise attenuating mechanisms, the design of acoustic arrays can be "tuned" to reduce tonal sound emissions from compressors within a certain frequency range, while also affording some broadband attenuation, and several other, non-acoustical benefits.

Introduction

For operators of natural gas storage and transmission facilities, which routinely employ gas turbines, environmental noise emissions can be an important consideration, toward operating harmoniously with the surrounding community, and complying with applicable environmental noise regulations. Of particular concern can be the tonal "whine" generated by the gas compressor which, because of its distinctive sound quality, has greater potential to disturb. In some jurisdictions, acoustical penalties for tonal sound emissions are stipulated in noise regulations. While traditional noise control options such as acoustical silencers, enclosures, barriers and lagging are designed to attenuate secondary sound emissions (i.e. from up or downstream piping, compressor building ventilation openings, etc.), none of these measures is aimed at directly addressing the source of noise itself: the gas compressor.

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 and to have 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 these legal obligations and ensure that they 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.

Noise Sources at Gas Compression Facilities & Traditional Control Measures

Gas turbines are commonly employed at natural gas storage and transmission facilities, which are often found in relatively rural areas where noise limits can be restrictive, and background sound levels are low (thereby increasing the audibility of such a facility at greater distances). A typical natural gas compression facility is comprised of several compressor plants, each hosting a gas turbine engine generating upwards of 30,000 kilowatts (40,000 horsepower); therefore, implementing adequate noise control in order to comply with regulatory limits and to minimize disturbance to neighbours can be a formidable challenge.

The most significant sources of noise at a typical natural gas compressor plant include the combustion air intake and exhaust of the gas turbine engine, the casings of the gas turbine engine and gas compressor (the latter of which includes a distinct tonal “whine”, discussed in greater detail in the next section), and above-grade suction and discharge gas piping. Almost invariably, the gas turbine engine and gas compressor are housed within a building; in many newer installations, the gas turbine is housed within an enclosure, inside the building (which makes for a more comfortable work environment for personnel who may spend any significant amounts of time inside the building while the equipment within is operating). Compressor buildings can be acoustically rated, with wall constructions that incorporate sound absorbing materials (to control reverberation inside the building) and massive outer skins with sound insulating doors to contain noise within. All other openings in the building, to facilitate

Figure 1: An industrial gas turbine combustion exhaust silencer.

ventilation air ingress and egress, can be fitted with acoustical louvres or silencers, which are effective means of controlling noise emissions to the outdoors from such openings. Likewise, noise from the combustion air intake and exhaust systems of the gas turbine engine (as well as the ventilation openings for the associated enclosure, if applicable), can also be effectively controlled with intake/exhaust silencers, although high performance silencers can be quite large (see Figure 1) and costly.

Figure 2: Fully enclosed above-grade gas piping and valve.

Noise emitted from above-grade piping can be a particular challenge, especially from piping that leads directly to/from the gas compressor. Noise generated by the gas compressor is transmitted through the gas medium in the piping, and radiated to the environment through the piping walls; the closer the piping to the gas compressor, the greater the noise emissions. While it is possible to control noise from above-grade piping with acoustical enclosures (see Figure 2), this can be prohibitively expensive for sites with extensive amounts of large diameter above grade piping (and associated valves/scrubbers), not to mention it creates challenges for maintenance and inspections.

Figure 3: Above-grade gas piping with acoustical lagging applied.

A commonly employed alternative to full acoustical enclosures to control piping noise is acoustical lagging (wrapping). Like an acoustical enclosure, the function of lagging is to contain and dissipate a portion of the sound emitted from a vibrating surface (i.e. the gas piping). However, because lagging makes full-surface contact with the 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. Thus, there are practical limitations to the amount of attenuation that can be achieved through the application of acoustical lagging.

Gas Compressor Noise

As noted in the previous section, one of the most significant noise generators at a gas compression facility is the gas compressor itself. Coupled to a high-powered gas turbine engine, gas compressors are comprised of multiple, increasingly restrictive stages of rotating blades and stators which draw gas through the suction piping, compress it, and expel it to the discharge piping at high pressures. This process generates several by-products, including heat, and significant amounts of noise. The interaction between the rotating impeller and the stator, particularly at the exit of the impellor and the inlet of the diffuser, generates discrete noise peaks (tones). The most prominent of these tones occurs at an acoustic frequency that is a function of the number of blades in the impellor and its rotational speed, and is referred to as the “blade pass frequency”; additional tones may be audible and/or measurable at higher harmonics (multiples of the blade pass frequency), along with broadband noise. Figure 4, below, shows the results of a narrowband frequency acoustical measurement of a gas compressor, showing tones at the blade-pass frequency (at approximately 1,160 Hz), and multiple higher harmonics.

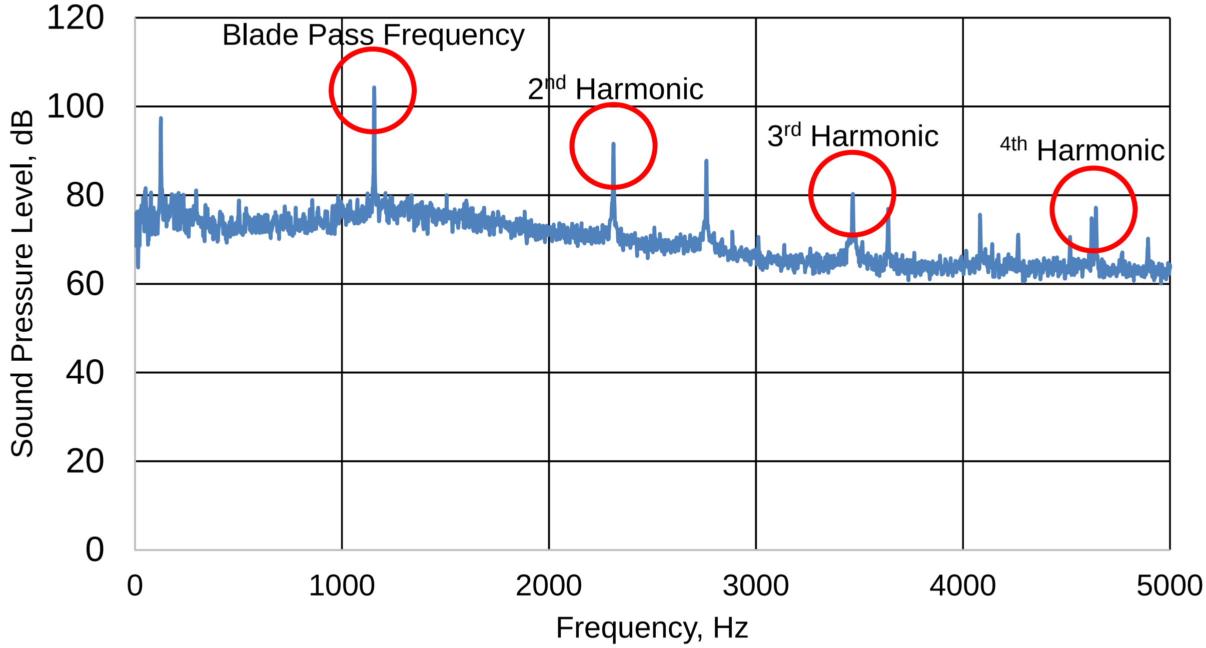

Figure 4: Narrowband acoustical signature of a gas compressor showing blade-pass frequency tone, and higher harmonics.

As noted above, noise generated by the gas compressor is emitted to the outdoors via multiple transmission paths: from the exterior casing (into the compressor building, and ultimately outdoors via the building walls/roof/doors and ventilation openings) and through the gas medium itself, exciting the walls of above-grade suction and discharge piping, which vibrate and radiate noise to the outdoor environment. This “piping noise” is concentrated at the blade pass frequency, which is perceived by listeners as a tone. Typically, the blade pass frequency falls within a range at which the human auditory system is most sensitive, making piping noise particularly audible, and thus potentially more likely to disturb neighbouring residents. In many jurisdictions with regulatory limits for noise, the applicable limits include a penalty for tonal sound, given its distinctly audible nature and greater likelihood to disturb. Therefore, noise from gas compressors is of particular concern in the context of developing noise control strategies for natural gas storage and transmission facilities.

Acoustic Arrays

The traditional approach to controlling noise emitted by gas compressors are “brute force” in nature. In particular, mitigating piping noise by employing measures such as acoustical enclosures or lagging (which is sometimes supplemented with noise barriers) can be expensive, and limit access to piping and associated valves, etc. for inspection and maintenance. Moreover, these measures are aimed at containing noise downstream of the source. In contrast, acoustic arrays are designed to limit the generation of noise from gas compressors at the source.

There are two types of acoustic arrays that are typically employed in gas compressors: a flat plate configuration which is installed inside the gas compressor body at the diffuser discharge, and a pipe configuration that is installed in the compressor inlet and discharge pipes. In either configuration, the acoustic array relies on the physics of a side branch Helmholtz resonator, which consists of a hollow cavity with a relatively short and small diameter neck that is oriented perpendicular to the gas flow. As acoustic pressure fluctuations impinge on the opening, the “slug” of air in the neck compresses the air inside the cavity; acting like a spring, the pressure in the cavity then pushes the slug of air in the neck outward. This process repeats many times per second, at a frequency that is dependent upon the relative dimensions of the cavity and of the length and diameter of the neck. As the slug of air in the neck of the resonator moves back and forth, acoustic energy is dissipated by surface friction and vortices generated along the walls of the neck. In addition, incident sound waves are reflected within the cavity with a phase shift, which partially cancels the noise travelling in the bulk gas flow.

By varying the dimensions of the cavity and the length and diameter of the neck, a Helmholtz resonator can be tuned to respond (i.e. resonate) at a particular acoustic frequency. Using this principal, acoustic arrays installed in a gas compressor use many Helmholtz resonators that are tuned to reduce sound within a particular frequency range, targeting the blade pass frequency of the compressor. Multiple arrays can also be “stacked” in order to provide attenuation over a larger frequency range (in case the gas compressor operates at different rotational speeds), or over multiple frequency ranges (to attenuate sound at higher harmonics of the blade pass frequency).

Dresser-Rand, a manufacturer of gas compressors commonly employed at natural gas transmission and storage facilities, has patented acoustic array technologies (US patents US 6,550,574 and US 6,601,672) and have been installing them in gas compressors for well more than a decade, and successfully demonstrated reductions in sound of 10 decibels or more at the blade pass frequency and higher harmonics.


Figure 5: Photo of one half of a flat plate acoustic array.

A gas compressor acoustic array is an effective alternative to more traditional means of mitigating environmental sound emissions at a natural gas compressor station, such as acoustical enclosures and lagging. By limiting the amount of sound that is emitted from the gas compressor at the blade pass frequency and higher harmonics, an acoustic array serves to reduce the overall sound emissions from a natural gas compressor facility toward complying with regulatory requirements, but also to reduce audibility of the station for neighbouring residents. If the reduction in tonal sound emissions from a gas compressor is great enough, an acoustic array may alleviate the application of tonal penalties applied in some regulatory jurisdictions. Moreover, effectively mitigated sound emissions from the gas compressor can reduce costs associated with controlling noise emissions from other sources, or create “acoustical headroom” to allow for expansion of a given facility. Reduced sound emissions from a gas compressor casing can also lower overall sound levels inside a compressor building, making it a more comfortable place to work. Additional benefits of acoustic arrays, beyond reducing sound emissions, include reduced unsteady aerodynamic load on impeller blades and diffuser vanes, as well as reduced pipe vibration which improves structural integrity and instrumentation life.

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 some number of decibels 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.

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).

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