Testing Building Envelope Leaks With Airborne Ultrasound

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ABSTRACT

The use of infrared (IR) thermography to locate water leaks and energy loss around building envelopes has been well documented. At times negative influences such as lighting conditions or line-of-sight accessibility might compromise the accuracy of the results. There are situations in which the procedure can be enhanced with the use of ultrasound technology. In some instances air flow conditions can produce detectable ultrasounds, but in most situations an artificial ultrasonic source must be used. The most common method for locating faulty seals or leak paths is called the ultrasonic "tone test". This incorporates the use of an ultrasound detection instrument with one or a series of multiple arrays of ultrasonic transmitters. Placement of the transmitters at strategic points along the subject test area allows inspectors to detect a path of sonic penetration, which will indicate the source of a leak. The technology along with an overview of the instrumentation and the methodology for tone generator placement and detection will be reviewed in this presentation

Keywords: Leak detection, air Infiltration, faulty seals, and energy loss.

INTRODUCTION

It is often quite possible to locate heat loss and leakage through building envelopes and containment walls utilizing infrared thermography. However there are conditions that are not well suited for infrared such as limited temperature differentials, poorly emissive targets, or extreme lighting conditions. When those conditions exist, ultrasound can prove a viable alternative.

Airborne/structure-borne ultrasound instruments have become an important accessory for infrared thermographers because these instruments will hear what infrared might not see. Some of the common applications in which IR cameras and ultrasound have been integrated include detection of underground leaks, inspection of steam traps and valves, and electrical and mechanical equipment.

In order to test building envelopes and walls ultrasonically, the use of a specialized test called a tone test is used. In order to understand the value of this procedure, it is important to understand how the technology works.

ULTRASOUND BASICS

Ultrasonic technology is based on the sensing of high-frequency sounds. Ultrasound is considered to start at 20,000 cycles per second, or 20 kilohertz (kHz). This is considered the high-frequency threshold above which human hearing stops. The range of human hearing covers frequencies of from 20 cycles per second (20 Hz) up to 20 kHz. The average human high frequency threshold is 16.5 kHz. Most ultrasonic instruments employed to monitor equipment will sense from 20 kHz up to 100 kHz.

These frequency comparisons are important to note because there are differences in the way low frequency and high-frequency sounds travel, which help us understand why ultrasound can be effectively used to locate the source of a leak.

Size Differences – It Matters

There are substantial differences in the size or wavelength of low frequency, audible sound waves and high-frequency/ultrasound waves. Audible or low- frequency sound waves will range from ¾" to as large as 56'. Ultrasound waves range from 1/8" to maximally 5/8". The physical differences in wavelength help us understand why ultrasound has an advantage in leak location. Low-frequency sounds, being large, tend to maintain a high intensity of sound volume over greater distances than high-frequency sounds. In other words, high-frequency sounds will not travel as far as low frequency sounds. Therefore, the amplitude of high-frequency sounds will fall off rapidly as the waves move away from the sound source.

To better understand the difference between low and high frequency sounds, imagine sitting in your car. The windows are closed and you are stopped at a traffic light. Along comes another car and stops beside you. As you sit there you become aware of rhythmical low-frequency vibrations. You hear and feel them. You become aware that your neighbor is playing the radio with the volume way up. His windows are rolled up but you do not hear the music or the words, you only "feel" the bass of the beat. These are low-frequency sounds. They are so large that they travel from the interior of the neighboring car through the air space between the two vehicles, through your car exterior to you. You do not hear the rest of the music because it is in a higher-frequency domain.

Low-frequency sounds can be considered omni-directional. They are so large it is often very difficult to locate the emitting source.

In comparison, high-frequency sound waves tend to be localized and directional in nature. For this reason, it is often easier to locate a sound source using high-frequency detection instruments.

Ultrasound Instrumentation

Instruments based on the technology of airborne/structure-borne ultrasound are referred to as ultrasonic translators. They receive the inaudible high-frequency sounds and electronically translate them down into the audible range through a process called heterodyning. The heterodyning method works in a similar fashion to AM radio. While we cannot hear radio waves, this method helps us easily identify different voices and musical instruments when we listen to the radio. Similarly this heterodyning process provides an accurate translation of ultrasound produced by operating equipment and enables users to readily identify one sound component from another. Most ultrasonic translators provide feedback two ways: through headphones and on a meter where the amplitude of these sounds can be viewed as intensity increments or as decibels.

Most instruments come equipped with interchangeable modules for scanning operations as in leak detection and electrical inspection where the instrument is used to detect airborne ultrasounds. A contact or stethoscope module is also included with these detectors and is used to locate structure-borne sounds such as in mechanical operations, valve inspection, or leaks behind walls and underground.

TONE TEST

When the conditions are such that it is difficult to detect a leak with infrared cameras and it is difficult to use standard ultrasonic leak detection methods such as creating pressure or vacuum fluid flow conditions, then an ultrasonic tone test may be used. This method uses an ultrasonic transmitter called a “tone generator.”

This test is conducted by placing an ultrasonic transmitter inside (or on one side) of the test item. The warble pulse-signal from the ultrasonic transmitter will instantly “flood” the test item. The transmitted ultrasound will deflect off solid surfaces but will penetrate through leak holes, faulty seals and gaskets. Depending on configuration and material, even thin spots in certain metals can be vibrated by the signal. By scanning for sonic penetration on the exterior surface (or opposite side) of the test item with the airborne ultrasonic detector, the leak will be detected. It will be heard as a high-pitched warble tone, similar to that of a bird chirping.

For inspecting large areas, multiple tone generators are strategically placed in various locations to produce intense, uniform ultrasound within the test area.

CASE HISTORIES

1. Noisy, leaky window. A corporate tenant that occupied most of a large high-rise office building in New York City was experiencing wind noise and water leaks around one section of the building that contained the corporate boardroom. Windows in the corporate boardroom under high velocity wind conditions produced disturbing whistling sounds. In addition, when a rainstorm occurred with high winds, the rainwater would be pushed through the exterior wall onto the ceiling area of the room. Having spent many man-hours looking for the leak and countless dollars attempting to waterproof the area, the building owners decided to employ ultrasound technology.

The corporate boardroom was high up (around 40 stories above ground) and access to the leak site was limited. Therefore the strategy included a two-man operation: one with a transmitter and one with an ultrasound detector. Both were equipped with “walkie-talkies” for voice communication. One of the inspectors holding a tone generator was sent up the building exterior on a window washer trolley while the other was positioned in the conference room with an ultrasound detector.

The procedure for the test involved moving the tone generator in sync with the ultrasound detector. The tone generator would be angled around seals to enhance sonic penetration. The reason for this approach is that, in order for a generated ultrasound to flow through a leak path with potential multiple channels, the signal strength must be optimized in the direction of the flow path. When the inspector with the ultrasonic detection instrument heard a sound he would communicate with the other inspector to coordinate their movements and to help verify the sound penetration source.

The method for locating and confirming the leak incorporated the use of the signal strength indicator on the instrument and a rubber-focusing probe. If a leak sound was heard, the operator moved the instrument in the direction of the sound and kept following the sound until the loudest point was indicated. In some instances, as the leak site was approached, the sound may have been too loud for an inspector to determine the location. When this occurred, the sensitivity/headphone volume was reduced providing better discrimination in terms of direction and location of the transmitted signal. To confirm the leak site, the operator placed a conically shaped rubber-focusing probe on the scanning module of the instrument. He then pressed the tip against the suspected site. The reason for this is that the sound will remain at the same amplitude if the leak is present. If the sound level drops the indication is that the leak is elsewhere. If this occurs, the operator will continue to follow the sound to the loudest point and repeat the confirmation process.

The leak source was detected within five minutes. The cause for the problem was missing insulation between the building envelope and the window frame.

Following the window seal for sonic penetration will reveal the leak source.

2. Exhaust fumes entering building. A major publisher's mainframe computer room is in one of the Rockefeller Center buildings. It is situated directly above an underground loading dock. The loading dock is about 100 feet by 100 feet by 20 feet high and holds 4 bays for tractor-trailers. During working hours the loading dock is busy with trucks entering and exiting to load and unload cargo.

An operator working in the computer room began to feel nauseous on an almost daily basis. The Operator became ill often and complained of smelling the exhaust fumes emitted from the trucks as they idled in the loading dock area. A decision was made to locate the source of the emissions leaking into the building. The Rockefeller building management team selected ultrasound as the method of approach.

Since the area was large and contained a multitude of leak path potentials, ultrasonic transmitters called multi-directional tone generators were used. Each of these tone generators had four transducers designed to maximize a 360^o transmission of ultrasound. The strategy was to place many of these tone generators around the loading dock to produce a uniform ultrasound.

A typical Multi-directional Ultrasonic Tone Generator. Placing a multiple array around the loading dock produced a uniform ultrasound field.

While scanning along the floor and walls of the computer room the inspector noted a recognizable warble tone and followed it to its loudest point. The source of the emission was coming from a conduit box, which was connected to a part of a ventilation system used to draw exhaust fumes away from the loading dock area. Once repaired, the fumes no longer entered the computer room and the operator was no longer bothered or sickened by the truck exhaust.

3. Air leaks in Navy ships. Another application of the tone method helped the U.S. Navy in its efforts to reduce man-hours. Large aircraft carrier bays must be checked for water tightness integrity on a regular basis. All hatches, doors and walls need to be checked for potential leakage. Some of the aircraft holding bays are so large they can contain the volume equivalent to that of many private homes and still have room left over for several large aircraft. The standard inspection method required that the compartment under test be pressurized with 3 psi of air and the opposite side of every seal or penetration be coated with a bubble solution while operators searched for bubbles. This took a 5-member team hundreds of man-hours to perform the task. Pressurizing the aircraft storage bays is extremely difficult because of the large open areas that need to be sealed. Looking for a better way, they investigated ultrasound.

A test was performed in which a training trailer was used. The trailer interior had been divided in two by a 1” steel wall. Test holes were randomly created and their locations noted. One side of the trailer was pressurized with air and inspectors performed a standard bubble test. The other side was inspected with the ultrasonic tone test. Multi-directional tone generators were placed to produce a uniform ultrasound and the exterior walls of the trailer were scanned for sonic penetration, which would indicate a leak.

The entire test, including the placement of the tone generators and the scan took less than 30 minutes. The pressure bubble test took almost twice as long. Convinced, the Navy managers conducted tests on aircraft carriers. The results were conclusive enough for the Navy to modify the standard for water tightness integrity inspection titled NAVSEA 9880.4025 to include Ultrasound Testing.

This is an example of a watertight hatch that requires testing. Notice the rubber gasket and multiple sealing levers to assure a proper seal.

CONSIDERATIONS FOR A SUCCESSFUL TONE TEST

a. Be sure to position the tone generator in line with the leak path.
b. For large areas place multiple arrays of tone generators to produce a uniform ultrasound field.
c. In some instances dirt and debris can block ultrasound, so if present, they must be removed.
d. Scan in line with the leak path.
e. Once detected, be sure to confirm the location of the leak.

CONCLUSION

There are situations where one technology will not detect the location of a leak. While infrared camera inspection is an effective technology, it can be enhanced for leak detection by incorporating airborne/structure borne ultrasound technology. When there are limited temperature differentials, emissivity issues, or pressure differentials that challenge infrared, the ultrasonic tone test can be an effective alternative.