Chapter 3

Acoustic principles

As many of the technologies currently used for leak detection involve acoustics, it is important to understand some basic principles of leaks, and some of the general physics involved. The noise characteristics of a leak have been used for many years to locate leaks – listening on valves, hydrants, stop taps, or at the ground surface above the line of the pipe.

3.1 HISTORY OF ACOUSTICS

Many scientists and researchers over the centuries have experimented with sound and acoustic theory in order to discover and formulate solutions relating to a number of practical problems. One of the first people to experiment with underwater acoustics was Leonardo Da Vinci in 1490 and documented his thoughts on discovering that if you are on a ship and bring it to a halt, then place a long tube in the water you will be able to hear by placing your ear on the end of the tube ships that are far away. Isaac Newton subsequently developed mathematical principles which dealt with sound. However, a major step in the history of acoustics was made by Charles Sturm, a French mathematician and Daniel Colladon, a Swiss physicist. Their experiment took place on Lake Geneva in 1826 when they measured the time difference between a flash of light and the sound of a submerged bell. The experiment was a success and the speed of sound measured was 1435 metres per second over a distance of 17,000 metres. This was the first time that a quantitative measurement was carried out and this sound speed value remains within a margin of acceptance of around 2%. Modern acoustic theory was established and documented by Lord Rayleigh in 1877.

Underwater acoustics became extremely important with the start of the World War I with anti-submarine listening systems being developed. A number of echolocation patents were granted in Europe and the United States of America with Reginald A. Fessenden's echo-ranger being patented in 1914. In the same period in France, Paul Langevin and in Britain, A. B. Wood and associates were carrying out similar pioneering work. Active ASDIC (Anti-Submarine Detection Investigation Committee) and passive

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SONAR (SOund Navigation And Ranging) were developed during the war, enabling the first large scale deployment of submarines. Acoustic mines were also another great advancement.

The refraction of sound waves produced by temperature and salinity gradients in the ocean were first described in a scientific paper in 1919. The range predictions were experimentally validated by transmission loss measurements.

Applications of underwater acoustics developed during the next two decades after the First World War. In the 1920's, commercial developments included the fathometer, or depth sounder and natural materials were used for the transducers. By the 1930's sonar systems incorporating piezoelectric transducers made from synthetic materials were being used for passive listening systems and for active echo-ranging systems. These were used extensively during World War II by both submarines and anti-submarine vessels.

Advances in the theoretical and practical understanding of underwater acoustics have been aided largely in recent times by computer-based techniques. The methodology applied today to detect water leaks using leak-noise correlators and noise loggers is based on the principles of underwater acoustics.

3.2 PROPAGATION

Water escaping through a leak creates a noise. The sound waves propagate along the pipe wall, fittings, surrounding ground and especially via the water inside the pipe. If the pipe wall were completely rigid, the sound would propagate with a velocity of approximately 1485 metres per second. However, the pipe material is always elastic to some degree. This elasticity causes attenuation of the pressure wave as it progresses down the pipeline.

The sound velocity in water pipes depends on the pipe material and the ratio between the diameter and wall thickness. For metallic pipes, the sound velocity slows down to about 1200 m/s, although the metal absorbs only a fraction of the sound energy and the sound still travels quite far. Plastic pipes are much more elastic, reducing the sound velocity to 300–600 m/s. Furthermore, the sound energy is more easily absorbed causing the sound waves to become weaker and weaker as they travel along the pipeline.

3.3 RESONANCE

Every pipe will exhibit a certain resonant frequency, if only longitudinal sound waves are considered (circumferential resonances will also appear but are of less importance). This resonant frequency is dependent upon the physical dimensions of the pipe and also upon the velocity of sound. It will therefore be particularly low for plastic materials, but also low for metal pipes of larger diameters. It can often be as low as around 10 Hz, which is well outside the perception range of the human ear (20–20 000 Hz in a healthy young person).

3.4 ATTENUATION

Higher frequencies are always attenuated more strongly with distance than lower frequencies. One example can be whales in the ocean, who communicate over enormous distances at subsonic frequencies. Another is distant thunder, which is only perceived as a low frequency rumble. However, even low frequencies are eventually attenuated over long distances.

When a leak noise is attenuated enough, it will be masked by other noises such as traffic, and ambient noises from effects within the pipe (such as turbulence resulting from rough surfaces) until ultimately even an expert cannot discern the leak sound.

Low frequencies are less attenuated and travel farther before they drown in the ambient noise. The snag is that human hearing cannot respond to the lowest frequencies.

The attenuation of a sound wave is small at resonance. Below the resonant frequency, attenuation increases slightly with decreasing frequency, whereas above the resonant frequency attenuation will increase strongly with increasing frequency.

3.5 ACOUSTIC IMPEDANCE

Every material has certain acoustic impedance that is expressed as the product of its density and its speed of sound. If sound is travelling in a certain medium, e.g. water, and meets a medium with different acoustic impedance, e.g. air, part of the sound wave will be reflected back.

If the differences in acoustic impedance are great, almost all of the sound will be reflected. If on the other hand both media have the same acoustic impedance, the sound will travel through the boundary with no reflection. In practice, the studied case lies between those extremes, and reflection will be partial.

The air/water boundary will reflect practically all sound, because both the density and the speed of sound of the two media are so different. The water/steel boundary will also reflect most of an impinging sound, since both the density and the speed of sound of steel are much greater than the corresponding quantities for water.