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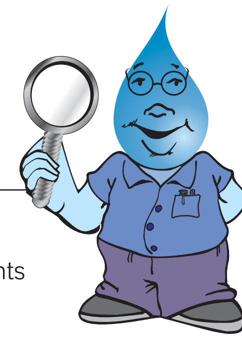

The Misconceptions of Acoustic Leakage Detection

By Stuart Hamilton and Dale Hartley

The article highlights practical developments over the last decade in managing water losses in public water supply distribution systems. To further improve the efficiency of acoustic leak detection, it is necessary to continue to explore techniques of measuring the wave speed in buried plastic water distribution pipes.

A Broken Water Main

Tin Can Telephone Concept

The Problem

Many engineers see acoustic leakage detection as the answer to their water loss problems and often believe that by simply installing equipment the leak can be found regardless of pipe material, diameter, pressure or the distance between the fitments. This highlights the misconceptions that many non-experienced engineers have of acoustic leakage detection, and often means the difference between success and failure.

Maybe an easier way to understand acoustics is the concept of the 'tin can telephone'. Everyone understands that to make this work the cord between the cans had to be pulled taught to enable the voice to be heard at either end, and if the string was allowed to slacken, then the voice could not be heard. The same basic assumption can be used to understand why leak noise transmits easier in metallic pipes (taught cord) than on non-metallic pipe (slack cord). It can also be assumed that the piece of cord can be of any length. If for hypothetical reasons the cord was 1000m long, would we expect the voice to be heard at either end? Of course the answer is 'no'. Again, using this assumption in acoustic leakage detection, why is it often assumed that sound waves from a leak can be heard by the correlator sensors over the same distance that the radio transmitters can transmit?

The most basic principle and fundamental requirement of correlation is that the sound waves from the leak (leak noise) must be heard at both sensors to allow the leak to be located. Obviously if the radios can transmit 1000–2000m and the leak noise is 'weak' due to leak type or pipe material and hence can only travel 500m, then this leak noise will not be heard at both sensors and the leak will not be located using leak noise correlation techniques (being heard at one sensor is not sufficient to complete a correlation). To emphasize the all too frequent lack of understanding that exists, below are some questions and answers recently asked during a tender process for the supply of acoustic leak detection equipment - in this case a correlator - where the responses show why the questions reveal a lack of understanding.


Acoustic Leakage Detection

How Far from the Correlator Can the Sensor Be?

This depends upon local conditions, but when referring to radio transmission distances this may on certain occasions be up to 2-3km. This will be less if digital frequency is selected (which depends more heavily on 'line-of-sight'). However, in a practical situation, to locate a leak, the leak noise must travel this far along the pipe, and this will be heavily influenced by many factors including water pressure, pipe material and pipe diameter.

Which is the Maximum Measurable Pipe Length a Leak Can Be Located Depending on the Material

Theoretically, the distance measured is entirely irrelevant, as in reality this distance is dictated by how far the leak noise travels. To ensure success the 'leak noise' must travel to both sensors and due to local conditions this can vary on every occasion.

Can You Guarantee the Equipment Can Transmit a Minimum Distance of 1km in a Build Up Areas

No. This can not be guaranteed, and radio transmission distance has no relevance in regards to leak location. To ensure success 'leak noise' must travel to both sensors and due to local conditions this can vary on every occasion.

Why Acoustic Leak Detection Doesn't Work as Effectively in Soft Materials

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The sound propagation or wave from an energy source in a pipe structure that does not contain a pressurized pillar of water, is sufficiently complex that this alone would not be suitable for an effective correlation. But luckily, with the pipe diameters and audible leak frequencies within a pressurized water distribution pipe network, there is a very homogenous mode of propagation of plain waves, which is ideal for correlation. What one measures is always - ALWAYS - the sound propagation in water; whether measured with a standard sensor 'accelerometer' on an outside contact point, or with a 'hydrophone' immersed directly in the water. Sound waves are in fact pressure waves which propagate in the water along the pipe network. If the pipe wall would be totally rigid, the sound would propagate with a velocity of approx. 1485m/sec. But in fact, the pipe material is never totally rigid. It is what we refer to as 'elastic' (even steel). This very fact enables us to 'measure' the pressure wave in the water with highly sensitive sensors (referred to as accelerometers) on the outside of the pipe wall. The usual point of contact is on the metallic valve spindle of a fully open valve.

To make things more complicated, this pressure wave not only travels in the water within the pipe (longitudinal), but it can always also 'resonate' outwards (circumferential), with the effect that it is no longer pressed forward with same vehemence. This has the effect that sound velocity slows down to about 1200m/sec in common metallic pipes. Since metal absorbs only a fraction of sound energy, sound within pressurised pillar of water still travels quite far.

In plastic pipes the effect is quite different. Plastic pipes are much softer or as above much more 'elastic', typically reducing the sound velocity to between 300-600m/sec, and in addition also absorbing sound energy. Therefore the sound waves become weaker and weaker as they travel along the pipe. There is also an additional and sometimes a more troublesome effect within plastic pipes this being the lack of high frequency noise. The high frequencies are much more 'deadened' per running meter than that of low frequencies, hence why on longer distances of plastic pipes, the low frequencies should always be measured to ensure that as much data as possible is recorded to optimize the correlation result.

To summarize this point the actual sound velocity in water pipes depends upon and is influenced by the pipe material or the 'elasticity module' and ratio between diameter and wall thickness. There is a formula to calculate the sound velocity, though unfortunately, the operator does not normally know the wall thickness and elasticity module; this is why the theoretical sound velocity as found pre-programmed in most correlators is always only an approximate value. This is why, to optimize the accuracy of results from a correlation only, a professional operator should always measure the real on-site velocity and use this in the calculation, but in reality this is seldom completed so to confirm the result of leak position prior to excavation a ground microphone is used to surface sound above the indicated leak position.

As a rule, the use of correlators is not always considered viable at extremely low frequencies, and so in many cases, especially on plastic pipes with low system pressures, the most practical methods of locating a leak available today still depend heavily on verification by means of 'surface sounding' along the path of the buried pipeline, with an electronic ground microphone or other similar device. Other acoustical methods can be devised, such as echo-sounding, but in reality the application in a water distribution network may prove hugely inhibitive, since a great number of echoes will occur from bends, service pipe connections, dimension changes and similar, and will prove to be extremely confusing to the operator.

And for the Scientists Amongst Us

With basic active leakage control knowledge it may be possible to locate a leak, but it must be understood that acoustic leak detection is very complex, and relies upon proven scientific theories.

Acoustics in Pipes

The general expression for the speed of sound in water is

c = 1410 + 4,21t - 0,037t2 + 11,4s + 0,018d m/s

where	t	=	temperature (degrees C)
	s	=	salinity (%)
	d	=	pressure (m water head)

This equation is, however, only valid in a 'free field' (such as ocean), but it can be used for assessing the influence of temperature, pressure and salinity. Salinity does of course not occur in water distribution pipes, and can be set to zero. It can be seen that pressure also plays a role, albeit a minor one. Temperature also has an influence over results, but in many countries the temperature in the water distribution system does not vary much over the year.

In a pipe, there is no 'free field', because the water body is confined by the pipe wall and so a sound will propagate only in one direction; although it can, while propagating, bounce against the pipe wall. The speed of sound will be influenced by the wall material - diameter, wall thickness, and its elasticity modulus. A general expression has been derived for the speed of sound in water-filled pipes:

$$V_p = \frac{V_o}{\sqrt{1 + \frac{(E_W \;.\; D)}{(E_p \;.\; d)}}}$$

Where	Vp	=	sound velocity in the pipe
	V0	=	sound velocity in free-field water
	Ew	=	modulus of elasticity of water
	Ep	=	modulus of elasticity of the pipe material
	D	=	inner diameter of pipe
	d	=	pipe wall thickness

Evidently this expression is not suitable for use during normal practical field work, and leakage technician will instead use pre-programmed tabulated values, or those derived from local experience and on-site velocity checks. But looking into the expression, it is clear that softer a material (Ep), lower the velocity of sound in pipe (Vp) will be. As a generalisation, the larger the pipe diameter (D), the lower the velocity of sound (Vp). In reality, the sound velocity depends on the relationship between pipe diameter (D) and its wall thickness (d); but as the pipe diameter (D) increases, so does its pipe wall thickness (d), explaining the decreasing sound velocity with increasing diameter.

Conclusions and Some Thoughts on Future Research

So it can be seen that many factors have to be considered when looking at acoustic equipment for leakage detection and much thought has to be given to why leaks can sometimes be located and sometimes not. It must also be considered that when purchasing such equipment that a good understanding of the equipment should be had and not be fooled into believing that the equipment will find a leak every time in every situation on distances greater than 1km, in reality and in practical urban site use, due to the surrounding influences, this is commonly less than 500m.

The research conducted in recent years has provided a much greater understanding of the way in which leak noise propagates in softer 'elastic' plastic water distribution pipes, and subsequently this has assisted manufacturers and research facilities in development of improved signal processing.

About the Authors

This article, by Stuart Hamilton and Dale Hartley, is part of the continued special series of articles for Water21 by the IWA Water Loss Task Force, highlighting practical developments over the last decade in managing water losses in public water supply distribution systems. The article was contributed by Gutermann Pty Ltd, Australia.

We look forward to your feedback on this case study. For further information on these authors, you can write to us at content@eawater.com