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LEAK DETECTION AND LOCATION IN PIPE-LINES BY ACOUSTIC CORRELATION TECHNIQUES

H.V. Fuchs, S. Shaw, G. Schupp

Fraunhofer-Institut für Bauphysik, Nobelstr. 12,
D-7000 Stuttgart 80

INTRODUCTION

Leakages in pipe-lines can cause considerable economic and environmental concern. In West Germany the annual loss of water amounts to over 100 million Marks. In view of the shortening supplies of unpolluted water and its increasing processing costs these losses can no longer be tolerated. Not only the environmantalists were concerned when in 1981 a million litres of aviation fuel leaked from the underground fuel supply lines at Frankfurt airport. Leaks in cooling systems of power stations may cause considerable safety risks.

In the past the search for leakages in underground pipelines was made using listening devices. The success and accuracy depends, among other things, on the type of pipe system and ground. An improvement in the searching technique has been made using acoustic correlation analysis.

THE CROSS CORRELATION TECHNIQUE

LOKAL, Leak Observation by Korrelation Analysis, is the name we have given the correlation techniques. Broad band noise from a leak is transmitted as plane sound waves along the pipe-line. Transmission over considerable distances is possible as attenuation of the plane waves is small. The leak noise is detected by two sensors mounted on the pipeline. They are separated by a known distance. Hydrophones or piezoelectric accelerometers are used to sense the sound waves. The signal from the sensors is electrically amplified and may optionally be filtered before being analysed by the correlator. A time delay between the two sensors is detected by the correlation analysis. The time averaged correlation function exhibits peaks which correspond to the time delays. The speed of sound in the pipe-line or the position of the leak may then be calculated from the measured time delay [1].

In practice some problems occur when a cable can not be layed between sensor and correlator or when a hydrophone cannot be mounted to the pipeline. Acoustic reflectors frequently obscure the correlation results by causing additional peaks which Akizuki et.al. [2] failed to interpret.

In a further development of the correlation technique the reflection of sound waves in a pipe network is therefore intentionally incorporated to produce interpretable time delays of the leak noise. With this technique only one sensor is required [3].

THE AUTO-CORRELATION TECHNIQUE

Sound reflectors have two advantageous properties for acoustic leak detection:

- o Reflection of unwanted interference sound away from the measuring section
- o Reflection of leak noise back down the pipe to the sound sensor.

In the latter property the time delay between the direct and reflected wave may be detected by using auto-correlation analysis.
From experience a reflection coefficient modulus greater than 0.1 may be implemented by the auto-correlation technique. The reflection coefficient for plane waves may be calculated using Table 1 . The table summarizes three typical arrangements of leak, sensor and sound reflector.

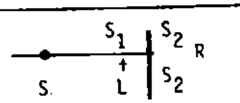
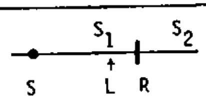
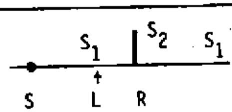
"T" joint		$r = 1-2\,m/(1+2\,m)$
Expansion or Reduction		$r = 1-m/(1+m)$
Side branch		$r = -m/(2+m)$

Table 1 Pipe network reflectors
m = S2/S1 is ratio of crossectional area
S is Sensor
L is Leak
R is Reflector

One generally finds that more than one sound reflector is present in the section of interest. In such a case there exists multiple leak to sensor propagation paths Δx. Fig. 1 illustrates a typical section of pipe with two sound reflectors R und R', one sensor S and one leak L; the propagation paths are listed in Table 2.

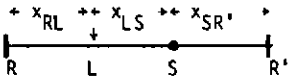


Figure 1 Section of pipe showing path length

	Path	Path length
1	L;S	x_{LS}
2	L;R;S	$2 \cdot x_{RL} + x_{LS}$
3	L;S;R';S	$x_{LS} + 2 \cdot x_{SR'}$
4	L;R;S;R';S	$2 \cdot x_{RL} + 2 \cdot x_{SR'} + x_{LS}$

Table 2

The first 4 shortest propagation paths

Path	1	2	3
1	0		
2	$2 \cdot x_{RL}$	0	
3	$2 \cdot x_{SR'}$	$2 \cdot x_{SR'} - 2\, x_{RL}$	0
4	$2 \cdot x_{RL} + 2 \cdot x_{SR'}$	$2 \cdot x_{SR'}$	$2 \cdot x_{RL}$

Table 3

Propagation path differences Δx

Auto-correlation peaks are expected at time delays corresponding to: $\Delta x/c$ where Δx [m] is path length difference as in Table 3 and c [m/s] is speed of sound. The auto-correlation function is a symmetrical function and therefore only the positive delays need be considered.

The distances ($x_{RL} + x_{LS}$) and $x_{SR'}$ are known, using a leak simulator at a known x_{LS}. c can be measured and finally the four time delays may be interpreted to extract the leak position x_{RL}.

In pracitcal applications $x_{SR'}$ may be chosen or happen to be very large compared to $x_{RL} + x_{LS}$ or zero. This reduces the number of measured time delays to 1.

Fig. 2 shows the plan of a water supply network in which a lèak was suspected. Cross correlation measurements between MS 1 and MS 2 led to the suspicion of the 100 diameter pipe. At the junction marked R the 100 mm pipe joins a 300 mm pipe. A sensor could be mounted at the point marked S, and the point marked R' is a closed valve. The reflection from the joint can be calculated to be $r = -0.89$.

As the sensor is directly mounted by R', $x_{SR'} = 0$. The length x_{RL} may then be found from the measured speed of sound, c = 1224 m/s and the time delay of 11.8 ms indicated by the marked peak in Fig. 3. The position of the leak is $x_{RL} = \tau \cdot c/2 = 7.22$ m. After excavation the leak was found to be at the given position.

Other applications of the auto-correlation technique have revealed leakages in overland pipe-lines exceeding a kilometer in length [3].

SCOPE OF APPLICATION

A new method of leak detection has been developed and tested successfully. On an aviation fuel test pipe-line the minimum leak rate detectable was 6 l/h at a distance of 100 m. Application of LOKAL is not restricted to metallic pipes. Apart from routine-like leak detection work in water mains networks and overland pipe-lines (in cooperation with the Technische Werke, Stuttgart) tests were also performed on district heating and sprinkler systems and gas filled pipes.

References

[1] Fuchs, H.V.; Shaw, S. "Akustische Ortung von Leckstellen in Rohrleitungen". In: Fortschritte der Akustik VDE-Verlag, Berlin, 1981, 391-400

[2] Akizuki, K. et. al. "Detection of water leakage point using cross correlation method". Proceedings of IMEKO Symposium on Flow Measurement and Control in Industry", Tokyo, Nov. 1979, 199-204

[3] Fuchs, H.V.; Shaw, S. "Leckerkennung durch akustische Korrelationsanalyse". FhG-Bericht 3 (1981), 26-31

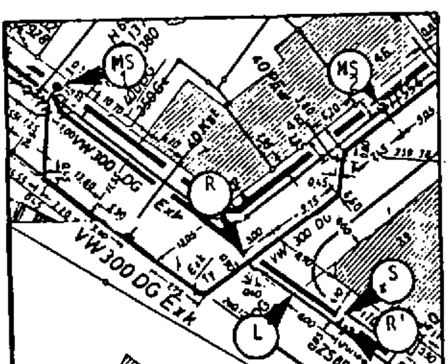


Figure 2

Plan of piping network showing two reflectors R and R', a sensor S, and the determined position of the leak L

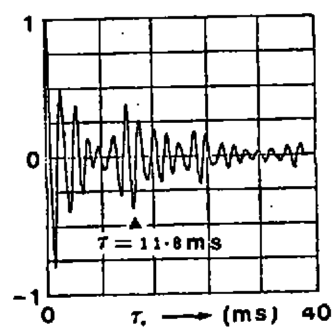


Figure 3

Correlation plot showing a maximum at τ = 11.8 ms