Vista Research Technical Memorandum No. 51

DETECTING LEAKS FROM TANKS AND PIPELLINES: THE STATISTICAL NATURE OF THE TESTING PROCESS

by
M. Fierro and H. Guthart
Vista Research, Inc.

SIGNAL AND NOISE

Testing a pipeline or storage tank for leaks is an example of the classical statistical problem of finding a signal in a background of noise. A *signal* is a discrete and measurable event produced by a leak, whereas *noise* is any process or phenomenon unrelated to a leak that can mask or be mistaken for the leak. In this memorandum, the concepts of signal and noise are described qualitatively.

MEASURING THE SIGNAL VS. NOISE

There are many sources of noise. First of all, noise is generated by the measurement system itself. This is typically referred to as *system noise*, and it defines the accuracy and precision of the measurement system. In addition, noise is present in the environment in which the measurements are made. This is typically referred to as *ambient noise*, and it can take many forms depending on the type of measurement being made. For a volumetric measurement system such as Vista's, the predominant source of noise is volumetric expansion or contraction due to temperature change of the fluid in the pipe or tank.

Leak detection systems, regardless of which technology they are based on, measure a combination of both signal and noise. Reliable detection can only be accomplished when the signal can be distinguished from the noise. By developing a detailed understanding of the sources of noise that limit system performance, Vista Research has been able to incorporate into its technology **analysis methods that reduce the noise.** The noise remaining in the data after these measures have been applied (the "residual noise") represents a significant reduction over the original amount of ambient noise.

In order to evaluate the effectiveness of a leak detection system, it is first necessary to determine the amount of residual noise. The noise associated with a leak detection method is the noise that is measured when there is no leak. In order to quantitatively describe the statistical properties of the noise associated with a particular leak detection method, one must conduct a large number of tests on one or more non-leaking pipes or tanks over a wide range of environmental conditions. This procedure will yield a measure of the magnitude of the noise that can be expected for a given leak detection system and, thus, an estimate of the magnitude of the signal (or leak rate) that can be reliably detected above this level of noise.

Every test of a tank or a section of pipeline is a measurement of the flow rate in or out of the tested section. Even when the tested section is “tight” (i.e., the actual flow rate is zero), the measured flow rate will not be exactly zero; moreover, it will be different each time a measurement is made. With a direct-measurement leak detection system, the distribution of these test results on a tight (i.e., non-leaking) pipeline or tank will follow a Gaussian (or “normal”) curve described by a probability, p,

$$p(\lambda) = k \exp(-\lambda^2 / 2\sigma^2)$$

where λ is the measured leak rate, k is a constant and σ is the standard deviation. This function reflects a finite probability for any finite magnitude of leak rate. The Gaussian probability function is characteristic of all direct measurement systems. It is *not* characteristic of leak detection systems that must be calibrated in the particular medium that surrounds the individual pipeline or tank. Figure 1 is a plot of the Gaussian probability function.

It is seen that this function is symmetrically distributed about 0. The indication of a leak in a pipeline or tank that is actually leaking will linearly displace the Gaussian function from 0 to LR, the leak rate.

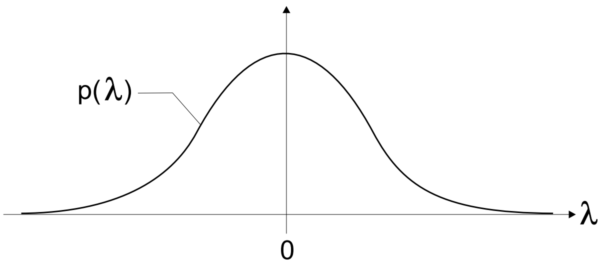
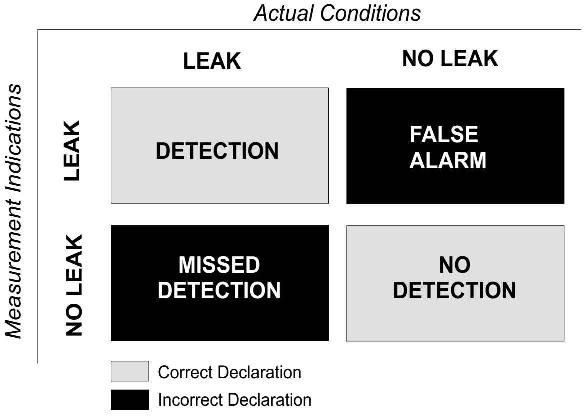


Figure 1. *A plot of the Gaussian probability function.*

The basis for declaring a leak is the threshold. In a non-leaking tank or pipeline, test results that fall within the threshold are considered noise, whereas those that exceed it are considered indicative of a leak. The threshold, therefore, is the sole criterion used to make the decision regarding the status of a pipeline or tank. The number of times this decision is correct versus the number of times it is incorrect defines the system performance.

THE CONCEPT OF PERFORMANCE

The concept of performance as a way to measure the effectiveness or reliability of a leak detection system evolved from research on underground storage tanks (USTs). Performance is defined in terms of the *probability of detection*, or P_D, which is the likelihood that a test will detect a real leak, and the *probability of false alarm*, or P_{FA}, which is the likelihood that a test will declare the presence of a leak when none exists. A related issue is the *probability of missed detection*, or P_{MD}, which is the likelihood that a test will not find a leak that does exists.



		Actual Conditions	
		LEAK	**NO LEAK**
Measurement Indications	**LEAK**	**DETECTION**	**FALSE ALARM**
	NO LEAK	**MISSED DETECTION**	**NO DETECTION**

□ Correct Declaration
■ Incorrect Declaration

The matrix at right shows the possible outcomes of a leak detection test. When the measurements match actual conditions, the result is a correct test decision—either the detection of an actual leak or the confirmation that none exists. If the measurements do not match actual conditions, the test decision is incorrect—either a missed detection or a false alarm. A reliable leak detection system generates tests that have a high probability of detection (or non-detection when there is no leak) and low probabilities of false alarm and missed detection.

DECLARING A LEAK

The threshold, T, is initially set to satisfy the required false alarm rate, the P_{FA}. The desired probability of detection, P_D, then determines the detectable leak rate for the chosen P_{FA} and P_D. How these quantities are determined is illustrated in Figure 2. In Figure 2a, the probability of false alarm is reflected by the shaded area under the *noise curve*, to the right of T. The shaded fraction of the total area, then, is the probability of false alarm. The probability of detection is represented in Figure 2b as the shaded area under the *displaced noise curve*, again to the right of the T. The distance between the means of the two Gaussian functions of Figure 2 is the detectable leak rate commensurate with specified P_D and P_{FA}.

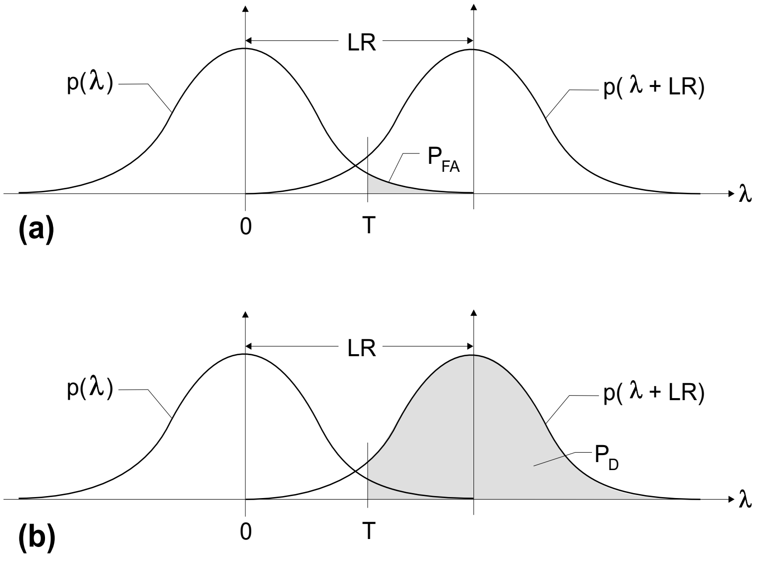


Figure 2. *Determining the detectable leak rate: (a) probability of false alarm; (b) probability of detection.*

The fundamental element of measurement system performance is σ, the standard deviation of the noise. The threshold is normally specified as a multiple of σ. For example, if a system is to have a P_D of 95% and a P_{FA} of 5%, then T is 1.65σ, and the detectable leak rate, LR, commensurate with a 95% probability is 3.3σ.

One of the characteristics of measurement systems having Gaussian test statistics is an improvement in performance when test results are averaged. If the results of N independent tests are averaged together, then the standard deviation of the averaged data is the standard deviation of a single test, σ, reduced by the square root of N, i.e., $\sigma_{AVG} = \sigma/\sqrt{N}$. Practically, this means that if one were to test four times per week, the averaged standard deviation, and therefore, the weekly standard deviation and the weekly detectable leak rate, would be smaller by a factor of 2 than the leak rate detectable in a single test. Increased frequency of testing and averaging of the results produce improved system accuracy without reducing the reliability of the result. Vista Research's leak detection systems are unique in possessing this attribute.

CONCLUSION

Vista Research's leak detection technology measures the volume change in the pipeline or tank, and provides, therefore, a **direct measure of the quantity of interest**. Other leak detection technologies measure a quantity other than volume and so their output must be re-interpreted and converted into volume. Under those circumstances, the accuracy of the measurement system is materially degraded unless the state of the system under test is known; for example, the amount of air in a pipeline will determine the transfer function between pressure and volume.

REFERENCE

H. L. Van Trees. *Detection, Estimation and Modulation Theory* (Part I). New York: John Wiley and Sons (1968), pp. 27, 37.