DNV·GL

TECHNICAL SUMMARY

SYNERGI PIPELINE SIMULATOR

Leakfinder

A better approach to real-time CPM leak detection

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HOW DOES LEAKFINDER WORK?

DNV GL's Statefinder's proprietary state estimation combined with sophisticated leak analysis algorithms is key to providing best in class leak detection performance and is designed to mitigate real world issues such as data uncertainties, poor communications, errors in as-built pipeline data, and incomplete product property information.

Leakfinder can operate with degraded or limited SCADA measurement data and also function in liquid lines that run "slack".

How does Leakfinder work? In simple terms, the input to a simulation system consists of two parts:

- Physical data – diameter, elevation, roughness etc
- SCADA data – flow, pressure, product data etc

All of this data contains some error, and the combined effect of this error is significant when trying to determine whether the hydraulic inconsistencies found in the model are the result of a leak or just noise. For example, a 5% error in viscosity combined with a 1% flow measurement error could have a bigger effect on a pressure loss calculation than a small leak; therefore the sensitivity threshold for most leak detection systems must be greater than the estimated sum of the error. This problem is further complicated by the fact that the error is not constant.

The following example explains Synergi Pipeline Simulator's unique approach to leak detection using a simple example system.

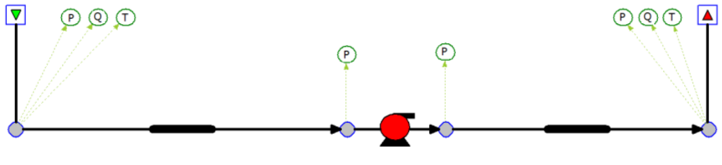

Figure 1 – Sample Pipeline System

Each of the pipeline sensors are subject to manufacturing and installation tolerances, RTU dead-banding and A-D conversion resulting in potential error as follows:

SENSOR	**ERROR**
Inlet Flow	+/-1 MBD
Outlet Flow	+/-1 MBD
Inline Flow at Pump	+/-2 MBD
Inlet Pressure	+/- 2PSI
Outlet Pressure	+/- 2PSI
Pump Suction Pressure	+/- 2PSI
Pump Discharge Pressure	+/- 2PSI

In one sense, this means that there are 7 known data points along the sample system. However, there is always uncertainty associated with each SCADA measurement and using each SCADA point exactly as it is recorded will lead to a hydraulically inconsistent modelled state.

When examining many SCADA measurements simultaneously it becomes necessary to construct a set of goals (equations) and employ an optimization technique that can be readily solved, which is exactly what Statefinder does. This is a distinctly different approach to that taken by many simulation software packages where only a subset of the SCADA data is used, such as pressure data. This allows other simulation packages to calculate a flow rate without considering the uncertainty in the measurements.

Applying Statefinder to the sample system in Figure 1 gives rise to a set of 7 unknowns, one for each point in the model connected to a SCADA device. The range of values for each of these modelled points is constrained by the SCADA device driving it. For example, since the inlet pressure has a potential error of 2.0, the pressure modelled cannot vary from the SCADA measurement by more than 2.0.

In addition to the constrained pressures and flows directly associated with SCADA devices, Statefinder also employs an unconstrained quantity at the location of each measured pressure called a Diagnostic Flow (DF).

One reason for this is to account for any un-modelled hydraulics that may occur. For example, if there is a leak in the system, the flow removal would be accounted for by a large negative DF calculated by Statefinder. The full Statefinder vector of unknowns (denoted as X_{SF}) for the sample system now contains 11 elements (7 measurements + 4 DF's).

The unknowns of Statefinder are calculated via a constrained least squares approach and user-defined weights with *m* equations and *n* unknowns.

The overall structure of the problem can be described by matrix algebra as:

$$(A)\,(X_{SF}) = (B)$$

Where **A** is an *m* x *n* matrix (*m*>*n*), X_{SF} is a vector of n unknowns and **B** is a vector of m goals. Since it is rarely the case that the equation can be solved exactly, it is common practice to rearrange such an equation into residual form as:

$$(A)\,(X_{SF}) - (B) = (R)$$

Where **R** is a vector of *m* residuals

As stated above, it is rarely possible for R=0, instead, the goal of this equation is to minimize the sum of squares of R (l2-norm), denoted as:

$$min\left(\sum_i r_i^2\right) = min\|R\|_2^2 = min\|AX_{SF} - B\|_2^2$$

Where $r_i \in R$

It is clear that the goal of all the DFs in the system is to equal 0. For pressures and flows, this form does not lend itself well to the minimization described in the above equation. Instead, the difference between the SCADA and model quantity is used as the unknown.

Many equations and unknowns are incorporated into a Statefinder system; these are referred to as JTS equations. Each of the JTSx equations has an associated weight, Wx, so the user can tune the model system based on what is already known about the system.

Once Statefinder has determined all modelled values in the system and all DFs, Leakfinder is now able to examine the modelled system to determine if there is a leak and, if so, where it is located. Leakfinder does this by determining if the DFs can be accounted for by the uncertainty afforded by SCADA data and hydraulic connections. The Leakfinder algorithm is similar to Statefinder in that it solves a constrained least squares minimization to a system of equations; however the Leakfinder system has more unknowns than equations and all elements of the unknown vector are constrained.

These key unknowns of the modelled state adjusted by Leakfinder include flows and pressures at all calculation nodes, upstream and downstream flows for each pipe, and a pressure differential across each pipe. Applying Leakfinder to the sample system above results in 29 unknowns.

Given the fact that there are more unknowns than equations (*m*<*n*) and if we did not limit the range of the unknown vector (X_{LF}), there would nearly always be a solution to the system of equations such that R = 0 so the adjustments are constrained by SCADA devices connected either directly or via hydraulic devices.

Let's look at a specific example from the sample system above. Suppose we simulate a leak of 5 MB/D in the system.

For both Statefinder and Leakfinder, the range of possible values for each $x_i \in X_{SF}$ or $x_i \in X_{LF}$ is limited by the potential SCADA error, any error that cannot be excused will result in a DF calculation at the location of each pressure meter.

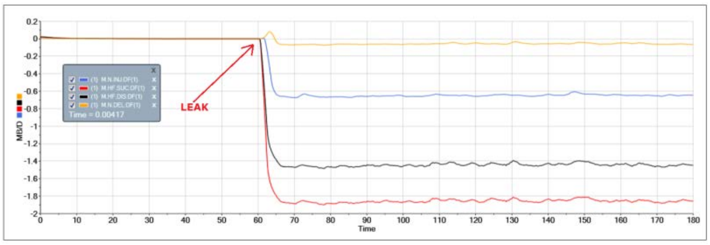

Figure 2 - DF Calculation at pressure meter locations

The DF's shown above are post-correction by Statefinder. Leakfinder will then try to excuse the DFs using the equations explained above. When all of the adjustment constraints have been reached and the calculated Leakfinder residual is greater than a configurable tolerance, Leakfinder will then generate an alarm and release information on leak size and location.

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