Technology Status Assessment

"REALTIME MONITORING OF PIPELINES FOR THIRD-PARTY CONTACT"

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Prepared for

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DISCLAIMER

INTRODUCTION

Third-party contact with pipelines (typically caused by contact with a digging or drilling device) can result in mechanical damage to the pipe. Because this type of damage often goes unreported and can lead to eventual catastrophic failure of the pipe,[1] a reliable, cost-effective method is needed for monitoring and reporting third-party contact events. Since over half of subsurface damage results from third-party infringement, the capability for detecting contact and locating encroachment would be greatly beneficial.

Several methods exist, or are being investigated, for monitoring and reporting third-party contact or activity near the pipeline. These include acoustic monitoring devices, continuous fiber-optic sensors buried alongside the pipe, satellite surveillance, cathodic protection monitoring, and methods that rely on telephone calls prior to digging. Because all of these methods have inherent limitations or are undesirable under certain conditions, the current project was initiated to investigate an alternate monitoring method. This method, impressed alternating cycle current (IACC), is capable of directly and continuously monitoring pipelines for third-party contact. Implementation of this method is relatively straightforward, and it can be retrofitted to existing pipelines without the need for excavating the pipeline.

The purpose of this technology assessment document is to describe the state of the art of pipeline monitoring, including positive and negative characteristics of existing technologies, and to present a comparison to the IACC technology being developed in the current project.

LITERATURE SEARCH

Literature searches were performed to obtain information about relevant pipeline monitoring methods. Searches made use of the resources of the STNEasy computerized search system. This included the following computerized databases:

- COMPENDEX (Engineering Index)
- ENERGY (DOE Energy database)
- FEDRIP (Federal Research in Progress)
- INSPEC (Database for Physics, Electronics, and Computing)
- NTIS (Government Reports and Announcements)
- PASCAL (Multidisciplinary scientific, technical, and medical database)
- ENTEC (German Energy Database).

Internet searches were performed using the search engine Google. Information was also obtained from the knowledge and contacts of Southwest Research Institute (SwRI®) personnel. A search for relevant patents was also performed using the United States Patent and Trademark Office web site (www.uspto.gov).

EXISTING MONITORING METHODS

Acoustic Monitoring Systems

The acoustic approach to pipeline intrusion monitoring is based on detection of impacts against the pipeline. Such impacts include backhoe strikes and the like. The history of this approach dates to the early 1990s. According to a Battelle chronology[2] of developments in this technology, British Gas first used the pipe wall as an acoustic signal carrier with a detector on the pipe wall. Tokyo Gas' approach was to use the gas column as the conductor with the sensor in the gas stream inside the pipe. Battelle followed those efforts with GRI-sponsored research that used sound conduction in the gas stream, but put the sensor on the outside wall of the pipe.

Battelle claimed a sensitivity range on the order of 5 miles for a backhoe strike. Parallel work by others, including ETOS Acoustics, Ltd. of Prague, Czechoslovakia, achieved similar results. The ETOS system, AMOS,[3] is claimed to detect hammer blows to the pipeline at a distance of 4 km.

Positive characteristics:

- A passive system that does not require any signal applied to the pipeline.
- Potential detection of other significant conditions such as leaks or product theft.
- Sensor deployment potentially no more frequent than approximately every 10 miles.

Negative characteristics:

- Susceptible to confusion from benign acoustic sources such as valve closures and routine maintenance operations.
- Reduced sensitivity to potentially damaging contact such as boring tools and drills, which do not have impact characteristics.
- Require sophisticated filtering techniques to reach acceptable signal/noise performance.

Two US patents were located with bearing on this technology:

- Pat. No. 5,333,501, Okada et al., "Abnormality Monitoring Apparatus for a Pipeline," August 2, 1994.
- Pat. No. 6,614,354, Haines et al., "In-Ground Pipeline Monitoring," September 2, 2003 (Covers the GRI/Battelle development).

Fiber-Optic Systems

The principle of operation of fiber-optic systems is that optical fibers are sensitive to stress applied to the fiber. Changes in the fiber's light transmission may be detected and located by using optical time domain reflectometry (OTDR). NYGAS (now Northeast Gas Association) has evaluated a system developed by Future Fiber Technologies, a system known as "Secure Pipe." The fiber detects vibrations and pressures generated in the area of the pipeline. The project is described at http://www.nygas.org/M-2002-011.htm.

The major work in fiber-optic detection of pipeline right-of-way intrusion has been carried out by the Gas Research Institute[4] (now Gas Technology Institute), most recently under funding provided by the Department of Energy. GTI work has concentrated on development of techniques to separate signals indicating potentially harmful encroachment from those indicating harmless encroachment.[5]

Positive characteristics:

- Continuous realtime monitoring.
- Range of tens of miles.
- Ability to detect and locate simultaneous encroachments at different locations along the pipeline.

Negative characteristics:

- Fiber must be installed in the right-of-way.
- Signals from benign pipe-loading events may mask the rare significant event.
- Sophisticated instrumentation and signal processing are required.

An on-line patent search at www.uspto.gov did not reveal any patents covering encroachment detection using optical fiber technology.

Satellite Monitoring

Commercial satellites can now monitor pipeline rights-of-way for ground motion and encroachment. For example, synthetic aperture radar (SAR) can be used to provide RADARSAT images that can be processed to reveal the presence of trucks or earthmoving equipment in proximity to the pipelines.[6],[7]

Remote sensing technologies have been used for some time to monitor natural resources. Twenty years ago, the industry had to rely on black/white aerial photography as the main tool for pipeline due to inadequate resolution of the satellite radar systems. Because newer systems can produce resolutions on the order of 1 m and provide hyperspectral data (>100 narrow spectral bands), remote sensing for pipeline encroachment detection is more feasible.

Much of the recent work in this area has taken place in Canada by the C-Core Company (www.c-core.ca).

Positive characteristics:

- Can cover the rights-of-way of an entire pipeline quickly and efficiently.
- Systems already in place that can provide pipeline coverage in parallel with other functions using existing satellites.

Negative characteristics:

- New software is needed to improve characterization of reflected targets.
- Urban congestion limits the application in highly developed areas.
- Monitoring cannot be done in real time.

Cathodic Protection Monitoring

A third-party contact detection system that monitors cathodic protection system potentials has been demonstrated by EUPEC RMS (www.eupecrms.com). This approach is based on changes in cathodic protection current paths when contact is made by a digging device. Changes in potential caused by contact with a backhoe have been demonstrated on a 250-foot test pipe.

Positive characteristics:

- Detects contact from backhoe strike as well as contact from drills and boring tools.
- Does not require digging to attach sensor; attachment is made to existing cathodic protection systems, thus allowing low-cost retrofitting of existing pipelines.

Negative characteristics:

- Detection range may be short.
- Sensitivity may be reduced by breaches in pipe coating.
- Relies on CP signals that may be variable.
- May be adversely influenced by 60-Hz (and harmonics) signals from other sources.

One-Call System

An alternate approach to monitoring is to prevent pipeline contact by observance of proper precautions and planning. The "one-call" systems in use in most states are an important element of such precaution/planning.

Since 1994, the primary component of damage prevention has been the one-call system. In order to promote the one-call system, the Office of Pipeline Safety (OPS) issued federal regulations that mandate participation in one-call systems for natural gas and liquid pipeline operators.[8] And in 1996, the OPS organized the Damage Prevention Quality Action Team to develop a national damage prevention campaign, now known as Dig Safely. The Dig Safely campaign was developed to address the problem of excavation damage to pipelines and other buried infrastructure. Since its formation, the Dig Safely campaign has grown tremendously, and is used throughout the country to promote damage prevention.

Dig Safely has a toll-free telephone number (888-258-0808) that can be used by anyone prior to excavation in any location in the country. The Dig-Safely web site (www.digsafely.com) also provides links to the state one-call systems that must be used prior to digging in any pipeline or other buried infrastructure right-of-way.

Statistics show that the incidence of third-party damage to pipelines has fallen significantly in states where one-call systems are in place.

Positive characteristics:

- Can prevent third-party damage or give immediate notification when it occurs.
- Gives the pipeline operator notice that activity is in his right-of-way.

Negative characteristics:

- Many excavation activities do not observe the one-call requirement.
- Some rights-of-way are not marked to prompt the one-call.

IACC

The IACC method consists of impressing electrical signals on the pipe by generating a time-varying voltage between the pipe and the soil at periodic locations where pipeline access is available (Figure 1). The signal, which travels down the pipe in both directions from the transmitter (Figure 1, left), consists of a time-dependent waveform designed to maximize IACC system performance in the presence of various sources of external noise. The signal voltage between the pipe and ground is monitored continuously at this transmission station. In addition, neighboring receiving stations with similar configurations (Figure 1, right), located some distance from the transmitting station, continuously monitor the received signal by measuring the pipe-to-soil voltage waveform. Third-party contact to the pipe that breaks through the coating changes (1) the impedance seen by the transmitting station and/or (2) the signal received at the IACC receiving stations that are located in the segment of pipe being contacted.

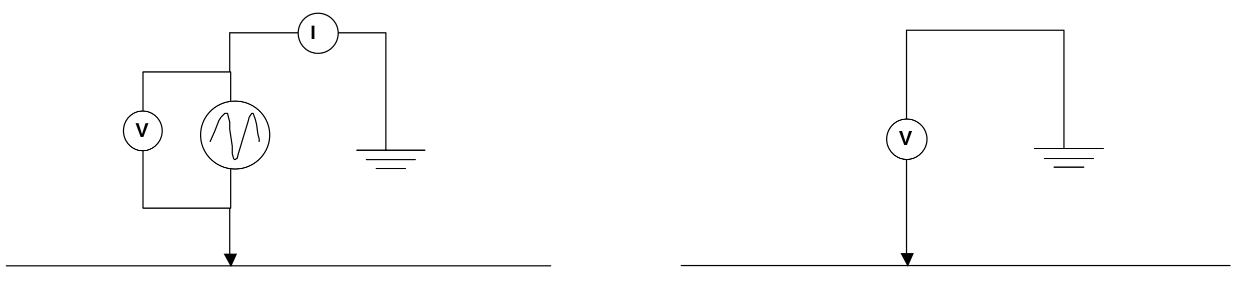

Figure 1. Schematic of IACC transmit station (left), showing time-varying voltage applied to the pipe, and receive station (right), showing measurement of pipe-to-soil voltage waveform

Initial work involving IACC[9] showed that the method is feasible. Projections from limited test results on an inservice pipeline showed that IACC was functional at a distance of 500 feet using excitation frequencies of 500 Hz and above.

The signal losses in the pipe are primarily capacitive, e.g. the pipe acts as one plate of a capacitor, the coating acts as a dielectric, and the soil acts as the other plate. Since capacitive losses are proportional to frequency, one approach to overcome problems with signal attenuation over long distances, and therefore extend the IACC range, is to reduce the operating frequencies below 500 Hz. Reducing the frequency by a factor of 5 to 10 should result in an increase in operating range of an equivalent factor. The use of lower frequencies, however, leads to potential interference from 60 Hz (and its harmonic frequencies) that are introduced from mechanisms such as cathodic protection systems. Advanced signal processing, such as digital filtering, can be used to process the IACC response and reduce interference effects, thus enhancing signal-to-noise ratio.

Positive characteristics:

- Active system that allows pipe excitation characteristics to be chosen to achieve optimum results.
- Does not rely on energy input from damage-creating mechanism that may be low-level and unpredictable.

- Detects contact from backhoe strike as well as from boring tools and drills.
- Does not require digging to attach sensor; attachment is made through existing cathodic test point, thus allowing low-cost retrofitting of existing pipelines.
- Can be temporarily applied for short-term monitoring of high-construction areas.

Negative characteristics:

- Detection range may be short.
- Sensitivity may be reduced by breaches in pipe coating.
- May have interference from cathodic protection systems.

COMPARISON OF METHODS

A comparison of the characteristics of the above pipeline monitoring methods is given in the following table.

Third-party monitoring systemd	Requires breach of coating for installation?	Equally effective for impacts and boring contact?	Range between sensors	Effective in urban congestion?	Provides full-time coverage?	Requires excavation for installation?	Development status
Acoustic sensing	Yes	No	10 mi.	Reduced	Yes	Yes	Field testing
Fiber Optic	No	Yes	10's of miles	Reduced	Yes	Yes	Field testing
Satellite monitoring	No	Yes	N/A	No	No	No	Under development
CP monitoring	No	Yes	Unknown	Yes	Yes	No	Field testing
One-Call System	No	Yes	N/A	Yes	N/A	No	Commercial
IACC	No	Yes	Several miles	Yes	Yes	No	Under development

CONCLUSIONS

Numerous methods are currently and potentially available for monitoring pipelines to detect third-party activity or contact. All of these methods have inherent limitations that reduce their usefulness under certain conditions. The IACC method to be investigated in this project offers distinct advantages that would allow it to be an attractive alternate or complementary approach.

[1] P. D. Panetta, et al., DOE Final Report PNNL-SA-35467, October 2001.

[2] B. Leis, "Real Time Monitoring to Detect Contact, Product Loss, and Encroachment on Transmission Pipelines," 54th API Pipeline Conference, April 2003.

[3] T. Salava, J. Kriz, and P Vojtech, "Acoustic Monitoring on High-Pressure Gas Pipelines," ETOS Acoustics Information (Prague 1998).

[4] R. H. Doctor and N. A. Dunker, "Field Evaluation of a Fiber-Optic Intrusion Detection System-FOIDS," GRI Final Report GRI-95/0077, December 1995.

[5] J. E. Huebler, "State of the Art in Detection of Unauthorized Construction Equipment in Pipeline Right-of-Ways," U.S. DOE NETL Infrastructure Reliability for Natural Gas (accessible through NETL.doe.gov).

[6] K. B. Fung, et al, "Application of Remote Sensing Data for Monitoring of Gas Pipeline Right-of-Way."

[7] C. Randell, "Operational Pipeline Integrity Monitoring Demonstration using RADARSAT."

[8] J. Caldwell, "One-Call on the Move Again," editorial in *Pipeline and Gas Industry*, November 1997, Vol. 80, No. 11.

[9] "Evaluation of the Use of Impressed Currents for On-Line Monitoring of Gas Pipeline," SwRI Final Report, Project 14.1791, for PRC International, November 2003.