REALTIME MONITORING OF PIPELINES FOR THIRD-PARTY CONTACT

SEMI-ANNUAL TECHNICAL PROGRESS REPORT NO. 4
April 1, 2005–September 30, 2005

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Cooperative Agreement DE-FC26-03NT41878
Southwest Research Institute® Project 14.10211

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Prepared for

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October 2005

ABSTRACT

Third-party contact with pipelines (typically caused by contact with a digging or drilling device) can result in mechanical damage to the pipe, in addition to coating damage that can initiate corrosion. Because this type of damage often goes unreported and can lead to eventual catastrophic failure of the pipe, a reliable, cost-effective method is needed for monitoring and reporting third-party contact events.

The impressed alternating cycle current (IACC) pipeline monitoring 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. The signal voltage between the pipe and ground is monitored continuously at receiving stations located some distance away. Third-party contact to the pipe that breaks through the coating changes the signal received at the receiving stations.

In this project, the IACC monitoring method is being developed, tested, and demonstrated. Work performed to date includes (1) a technology assessment, (2) development of an IACC model to predict performance and assist with selection of signal operating parameters, (3) investigation of potential interactions with cathodic protection systems, and (4) experimental measurements on operating pipelines. Based on information recently found in published studies, it is believed that the operation of IACC on a pipeline will cause no interference with CP systems. Initial results on operating pipelines showed that IACC signals could be successfully propagated over a distance of 3.5 miles, and that simulated contact can be detected up to a distance of 1.4 miles, depending on the pipeline and soil conditions.

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INTRODUCTION AND BACKGROUND

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, a reliable, cost-effective method is needed for monitoring and reporting third-party contact events.

The impressed alternating cycle current (IACC) pipeline monitoring method involves 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 at 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

The objectives of the proposed work are to further develop, test, and demonstrate the IACC monitoring method for detecting third-party contact with pipelines in real time. This method will allow existing pipelines to be retrofitted for monitoring without excavation because the technique uses existing cathodic protection (CP) test points. In addition, the method could be readily applied to new pipelines. Upon completion of the work, guidelines will be developed for use by a vendor to begin development of a commercial version of an IACC system.

RESULTS AND DISCUSSION

The sections and corresponding numbers below correspond to those used on the Research Management Plan.

1.1 Research Management Plan

A research management plan document was prepared and submitted previously.

1.2 Technology Status Assessment

A technology status assessment was prepared and submitted previously.

1.3 IACC Parameter Refinement

1.3.1 Modeling

This effort involves developing an equivalent circuit computer model to represent the electrical circuit formed by the pipe and its interaction with the earth (e.g. resistive and capacitative coupling). The model allows simulations to be performed to study the effects of signal characteristics (e.g. frequencies and excitation levels) on the IACC signals. These simulations will allow signal characteristics to be selected to maximize range and reduce interference.

During this reporting period, the model was updated to include lower pipe-to-soil impedance measurements that were determined from operating pipelines.

1.3.2 Signal Processing

The sensing approach that has been used prior to this reporting period utilizes a software-based matched filter operating on a chirp waveform that contains a wide range of frequencies. Because of considerable noise imposed on the pipeline at 60 Hz and higher harmonics (from power line coupling and active CP systems), it was also necessary to implement notch filters at these frequencies. This was done in software and was effective. One difficulty with this approach, however, is that the 60-Hz signals can be much larger (e.g. orders of magnitude) than the IACC signals. Since the signals are digitized prior to filtering, the dynamic range of the digitizer has to accommodate the larger 60-Hz signals and, therefore, only a limited dynamic range is available for the IACC signals. Therefore, resolution is lost.

An alternate approach is to implement a comb filter prior to digitization of the IACC chirp signal so that the interfering signals do not occupy a large portion of the dynamic range of the digitizer. This filter consists of a series of notch filters at 60 Hz and its higher harmonics. This should allow greater resolution and an improvement in the signal-to-noise ratio.

A comb filter was fabricated and was very effective for removing the 60 Hz and harmonics signals when operated with steady-state excitation. Use of a chirp excitation waveform with this filter, however, resulted in unsatisfactory results because there is a slight instability in the signal as the chirp frequency sweeps past each of the notch filter frequencies; this makes it difficult to resolve the small changes in IACC signal caused by third-party contact when using the chirp waveform.

An alternate sensing approach is being investigated. Lock-in amplifiers are commonly used to provide detection of signals buried in noise. Normal operation of a lock-in amplifier requires a reference signal that is at the same frequency and in phase with the signal to be detected. This allows the instrument to phase lock on the signal of interest and to reject signals at other frequencies. For IACC, the use of a reference signal in the conventional sense would require a physical or wireless connection between the transmitting and receiving stations. An alternate approach has been developed that is attractive for IACC. With this approach, separate oscillators with very high frequency stability (through the use of direct digital synthesis) are used at both the transmitting and receiving stations. Because these devices are highly stable, there is essentially no frequency drift, and thus the lock-in amplifier (at the receiving station) can be referenced to the transmitted signal without the requirement for a connection between the two. Thus, a reference connection is not necessary. Any frequency drift that does occur is over a relatively long period of time; this can be filtered from the signal because only short events are of interest for third-party contact.

Instrumentation was configured for this approach and was tested on the SwRI pipe and on the CPS pipeline at Leon Creek and shown to be viable. Initially, the lowest frequency that could be used with this instrumentation was 270 Hz; however, changes were later made that allowed operation at frequencies as low as 5 Hz.

1.4 Investigation of CP Interactions

The purpose of this task is to determine any effects of cathodic protection systems on the functioning of the IACC method and to determine any effects of the IACC signals on the CP system. The proposed IACC method applies an alternating current signal onto the pipeline. The signal is nominally 10 volts P-P at a frequency between 10 and 1000 Hz. Ground reference is a local ground rod at the transmitting site. There are three potential concerns about using this type of excitation:

1. Does the excitation present a shock hazard to pipeline workers or the general public?

2. Can the excitation initiate or accelerate corrosion of the pipeline?

3. Will the excitation interfere with existing DC cathodic protection systems?

In order to answer these concerns, the project staff did an information search that included questioning pipeline maintenance personnel and searching relevant literature. Findings are referenced to the three concerns above. Numerical data quoted are from Reference 1 below.

Shock Hazard. Most operating pipelines follow published US and Canadian standards that dictate a maximum safe voltage of 15 volts on operating pipelines. Our excitation is always kept within that limit even at the signal generator, the strongest signal point on the pipeline. Furthermore, the signal source we use cannot deliver enough power to harm a person who comes in contact with it. Therefore we conclude that the IACC system poses no shock hazard to pipeline workers or the general public.

Initiation or Acceleration of Corrosion of the Pipeline. Corrosion found on pipelines in the USA and Germany prompted research into the likelihood of AC currents either initiating or exacerbating pipeline corrosion. The investigation was triggered by finding significant corrosion on a pipeline that ran parallel to a railway using 16-2/3 Hz AC power. In addition, the soil resistivity was very low due to soil contamination from de-icing salt. Subsequent investigation concluded with guidelines for avoiding any AC current effects. These guidelines show that operation at AC frequencies from 10 to 60 Hz is acceptable if the current density is less than 20 A/m^2 and that operation above these frequencies is possible at even higher current densities.

The proposed IACC system is a low-power system that attenuates rapidly from the excitation source due to capacitive leakage of the signal from the pipeline to ground. It will not be able to deliver current densities that will initiate corrosion.

Interference with Normal CP Operation. The guidelines for avoiding interference with CP are the same as for avoiding corrosion. We do not anticipate any effect on existing CP. Our test results also show that we do not suffer any significant reduction in our effectiveness due to the presence of impressed current CP systems. IACC functions as well with the CP system on or off. The noise level from the full-wave rectified 60-Hz CP can be reduced by filtering out 60-Hz harmonics and by the natural rejection of the lock-in amplifier used to detect the IACC signal.

References. Numerical data quoted above are from Ref. 1. The other references agree in substance with Ref. 1, but have fewer numerical guidelines.

1. R. A. Gummow, R. G. Wakelin, and S. M. Segall, “AC Corrosion–A Challenge to Pipeline Integrity,” *Materials Performance*, February 1999, pp. 24–31.

2. N. Kouloumbi, G. Batis, N. Kioupis, and P Asteridis, “Study of the Effect of AC-Interference on the Cathodic Protection of a Gas Pipeline,” *Anti-Corrosion Methods and Materials*, **Vol. 49**, No. 5, 2002, pp. 335–345.

3. John Dabkowski, “A Review of AC Power Line Coupling Unto Buried Pipelines,” Paper No. 561, *Corrosion 98*, 1998, NACE International.

1.5 Contact Simulator

The contact simulator was completed, as described in the first report. During this period, the simulator was configured with a battery and inverter power supply, and all components were placed in a case for portable operation.

1.6 Pipeline Tests

1.6.1 Measurement of Pipe Parameters

It was initially believed that the electrical resistance between the pipeline and soil would be high because of the high resistivity of the pipe coating; however, initial testing showed a low pipe-to-soil resistance. This was further investigated by making pipe-to-soil impedance measurements on two San Antonio City Public Service (CPS) pipelines. It was determined that low pipe-to-soil resistance (similar to low-frequency AC impedance) was characteristic of all three pipelines, even though they had relatively new fusion-bonded epoxy coatings in good condition. For example, the low-frequency pipe-to-soil impedance was 3 ohms for the Leon Creek pipeline (16 inches in diameter by 1.5 miles long) and 14 ohms for the Calaveras Power Plant pipeline (8 inches in diameter by 0.15 mile). The low-frequency impedance between a ground rod (used for simulated third-party contact) and soil was 16 ohms for Leon Creek and 14 ohms for Calaveras.

According to Peabody's *Control of Pipeline Corrosion* (Second Edition), the expected DC resistance between a coated pipeline and ground should range from 0.02 ohms to 10 ohms for a 36-inch pipeline that is 10 miles long. The variation is caused by differences in coating quality and the presence of minor coating holidays. If we take the pipe-to-soil values from above and apply corrections for the diameter and length, we have resistances that vary from 0.047 to 0.207 ohms. These values fall within the expected values found in the literature.

The low pipe-to-soil impedance and higher ground rod-to-soil impedance is a significant factor for IACC third-party contact measurements because it reduces the influence of third-party contact on the impressed waveform. In effect, a third-party contact event results in a resistive path between the pipe and soil that is placed in parallel with the pipe-to-soil resistive path. However, because this resistance is higher than the pipe-to-soil path, the overall change in resistance is small; therefore, the change in IACC signal is small.

1.6.2 Detection of Impressed Waveforms

Measurements at CPS Leon Creek Site. An IACC field test was conducted on the San Antonio CPS 16-inch pipeline at the Leon Creek location using the lock-in amplifier approach. This was accomplished at excitation frequencies of 270 and 570 Hz. The IACC signal was successfully detected with the receiving station at a distance of 1.43 miles from the transmitter (the longest distance readily available on that pipeline), and simulated third-party contact applied at distances of 0.19 and 0.7 miles from the transmitter was also detected at 1.43 miles.

Measurements at Duke Energy Edinburg Site. Arrangements were made with Duke Energy for measurements on 6-inch and 30-inch-diameter pipelines near Edinburg in south Texas. The 30-inch line has accessible CP test points at approximately 0.5 mile (or closer) intervals; this allows tests of the IACC method in 0.5-mile increments. The 6-inch line has accessible points at approximately 1-mile intervals. Preparations for the measurements were completed. These included configuring the transmitter and contact simulator equipment in self-contained cases with internal battery power so that they could be easily transported between different test sites and left unattended during testing.

Tests were originally scheduled for the week of September 26, 2005; however, they were postponed, as it was necessary for the Duke Energy personnel to deal with issues arising from Hurricane Rita. The tests were rescheduled for the week of October 24. These tests have now been completed, but data analysis is still underway. A brief discussion of initial results follows.

The lock-in amplifier method was used for the tests on Duke Energy pipelines. The best signal propagation was achieved at low excitation frequencies, and a frequency of 10 Hz was chosen for most of the testing. This is the lowest frequency for which sufficient cycles would occur over a third-party contact event to allow reliable detection of the event. It was shown that the IACC signal could be readily propagated and detected over a distance of 3.5 miles, even in the presence of strong induced 60-Hz signals (apparently from power lines in close proximity to the pipeline). It was difficult, however, to detect changes in the IACC signal caused by simulated third-party contact over this distance. Simulated third-party contact with the 30-inch line was readily detected with the transmitter and receiver separated by 1 mile with the contact made at a distance of 0.72 mile from the transmitter.

1.7 Evaluation

Evaluation of the pipeline test results and development of design guidelines and specifications were initiated.

1.8 Technology Transfer

The Technology Assessment document was submitted previously.

1.8.1 Meetings

No meetings were held during this period

1.8.2 Deliverables

Documents were delivered per the project schedule. These included Semi-Annual Technical Progress Report No. 3, Informal Status Reports, Financial Status Reports, and Federal Cash Transaction Reports.

1.8.3 Milestones

Project milestones are shown in the following table. Because of initial unexpected results obtained from operating pipelines (low pipe-to-soil impedance), a 3-month time extension was granted to allow resolution of this issue. The milestone dates were revised accordingly.

Milestone	Due Date	Revised Due Date
Modeling and Simulations Completed	Complete	
Parameter Optimization Completed	Complete	
CP Interactions Determined	Complete	
Contact Simulator Completed	Complete	
Pipeline Testing Completed	6/1/05	11/05
System Demonstration	6/1/05	12/05
Data Evaluation Completed	8/1/05	12/05
Design Guidelines Completed	8/1/05	12/05

WORK ANTICIPATED IN NEXT REPORTING PERIOD

In the next reporting period, the final test will be performed on an operating pipeline, and data analysis from all tests will be completed. A demonstration will be performed, design guidelines for an IACC system will be completed, and the final report will be completed.

CONCLUSIONS

The IACC method is promising as a monitoring method for third-party contact. Based on information recently found in published studies, it is believed that the operation of IACC on a pipeline will cause no interference with CP systems. Initial results on operating pipelines showed that IACC signals could be successfully propagated over a distance of 3.5 miles, and that simulated contact can be detected up to a distance of 1.4 miles, depending on the pipeline and soil conditions.