MAGNETOMETER-BASED MEASUREMENTS OF STRAY CURRENT DISTRIBUTION ON CATHODICALLY PROTECTED GAS TRANSMISSION PIPELINE

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INTRODUCTION

Currents on gas pipelines are known to arise from intentional sources such as impressed current systems used for cathodic protection and from unintended and often unknown sources including local transit systems, power stations and a range of telluric sources. Under some conditions these stray currents can be large enough to present a potential threat to the integrity of the pipeline through accelerated local corrosion. This is even true for nominally cathodically protected systems if the magnitudes of the stray currents are sufficiently large.

The gas industry has responded to this issue by monitoring pipeline currents and by making changes in the pipeline environment as required. Typically, this monitoring involves the use of iR drop electrodes physically bonded to the pipe at selected positions [1]. These electrodes provide an effective measurement of pipe current. However, the need for electrical contact with the pipeline requires excavation and removal of surface protective coatings. This may not be always possible based on both cost and logistical considerations.

In this paper, we describe a new method of monitoring current distributions on a buried pipeline system using magnetic sensing and apply it to a significant problem of stray current interference from a metropolitan transit system. This problem of current distribution has immediate importance to some elements of the natural gas industry. Some of the benefits of the new method are: 1) It does not perturb the pipeline with any external signal, but only monitors the magnetic field produced by the existing currents on the pipe; 2) No contact with the pipe is required; 3) The instrumentation required is portable and relatively simple, hence measurements can be made at the location and with the spatial resolution required by the system under examination; 4) Both on-pipe and transverse current are determined; this provides added information about the electrical status of the pipe; and 5) The system has good spatial resolution and can locate the source of interfering current to an accuracy of several feet, thus pinpointing the problem for later correction. It can, of course, verify that the problem has been corrected.

Our measurements suggest that the conventional view that stray current interference from metro transit systems proceeds via ground connections with the gas pipelines is incomplete. For the two cases discussed here, the stray currents are injected on to the gas pipes from a single point. The portability of magnetometer based detection coupled with its spatial resolution (approximately equivalent to the depth of the pipeline) is mainly responsible for this finding.

STRAY CURRENT EFFECTS FROM A TRANSIT SYSTEM

Stray current on gas pipelines associated with a metropolitan transit system can be a potential source of corrosion. This is true even for cathodically protected pipelines, as illustrated in Figure 1 where the on-pipe current for a major gas transmission 26" pipeline is shown over a 600 seconds time period; the zero time was arbitrarily selected. The cathodic protection (CP) current was applied in the interval between 0 and 300 seconds while at the 300 seconds the CP was turned off. The current step observed in the figure corresponds to the total CP current. The current pulses which are observed along with the on-pipe CP current are due to the stray current. Note that the magnitudes of these pulses are comparable to the CP current itself. In addition, the number of pulses ranges from 200 to 400 pulses/hr varying with location and time of day. Since these stray pulses are bi-directional the pipelines can experience excess cathodic current (leading potentially to hydrogen embrittlement) or insufficient CP current for adequate protection. In either case, these stray current pulses can have an adverse effect on the gas pipelines. It is therefore important to identify where these stray currents are injected onto the pipeline and take steps to prevent this from occurring.

Test Site 1

The field map at Test Site 1 of the Pipelines A, B, and C area appears in Figure 2. The major features are: (i) A metro transit line terminates 450' south of the pipelines; (ii) A gas flow measuring station is located about one-half mile east of the metro station. There is an electric power cable which is connected to the gas pressure and flow rate measuring devices inside the station; (iii) Several sacrificial (magnesium) anodes are also connected to the pipes inside the station; (iv) A rail-

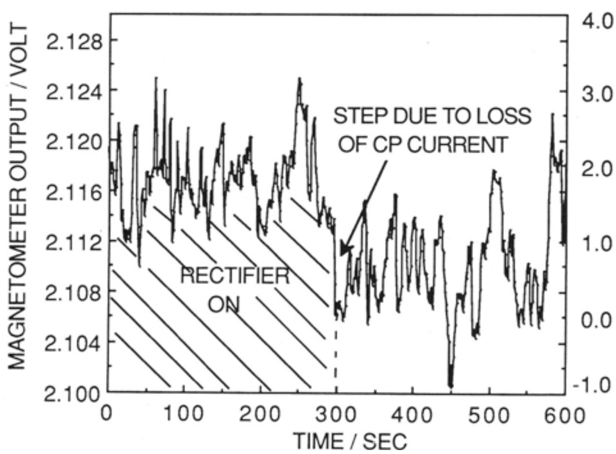

Fig. 1 Current-time plots on a 26" transmission gas pipeline; 0-300 sec, pipeline is under cathodic protection (CP); 301-600 sec CP turned off. In this figure as well as in the rest of the current-time records Y-axis has the convention as follows: left -- on-pipe current as read by the magnetometer and right -- after conversion to Amperes; conversion involves pipe depth value at each location.

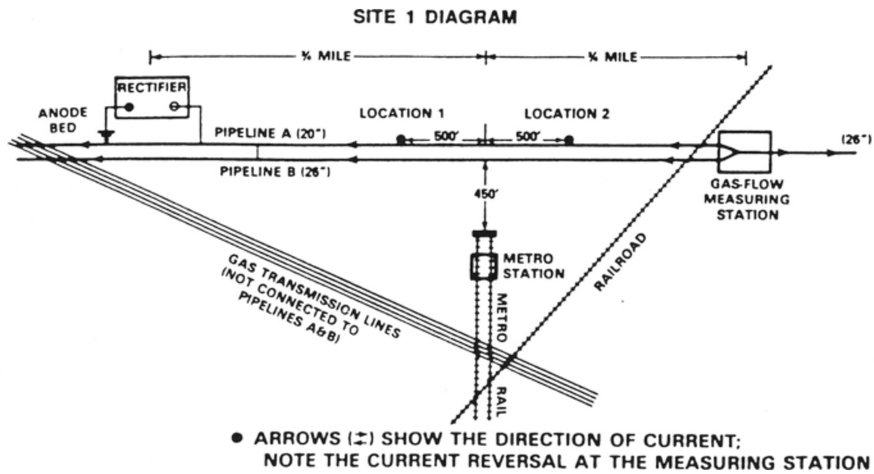

Fig. 2. Map of the Test Site 1. Features: Pipelines A, B & C, Metro transit line, gas flow-rate measuring station, a set of 4 gas transmission lines belonging to another company (and not connected to A & B), a railroad and a rectifier bed.

road crosses the gas pipe west of the measuring station; and (v) A rectifier and groundbed is located one-half mile west of the metro station. The pipes are steel, 26" (A & C) and 20" (B) in diameter. Pipeline A & B are west of the measuring station while C is east of it. They all have a 3' cover and are coated, wrapped and cathodically protected through the rectifier and remote groundbed.

Test Site 2

The field map of the Test Site 2 is shown in Figure 3. The 26" Pipeline D is the only gas transmission pipline in this location. The most important feature of this site is that the transit system crosses the transmission pipeline.

Other notable features in Figure 3 are: (i) A gas flow measuring station is located within 50' of the transit line; everything to the left of the road in the map, including the Pipeline D, is a part of the measuring station. The pipes in the form of elongated rings are called 'donuts'; pressure and flow-rate measuring devices are connected to these 'donuts'. An electric power cable is connected to the pressure and flow rate measuring devices and the pipelines are connected to the neutral. This is a common feature between this site and the one at Test Site 1. (ii) The gas pipes inside the measuring station are cathodically protected by rectifier and anode beds; (iii) A few sacrificial (magnesium) anodes are also connected to the gas pipes; (iv) A major four-lane road system is located between the measuring station and the transit line. This road carries a heavy volume of traffic.

EXPERIMENT

The measurements reported here monitor on-pipe currents. Two methods were employed: (i) the iR drop stations available on A and B were used at locations where they were available; (ii) magnetometers placed on the earth above the pipe were used at the iR drop electrodes and at other points along the pipe. (The magnetometer does not require any connection to the pipe.) In both cases the pipe current was monitored using a high accuracy computer controlled data acquisition system for later analysis. The conversion of the magnetometer output signal to current was determined experimentally using a standard current source under controlled condition. The iR drop calibration was based on a 2A/1MV conversion factor provided by the gas company.

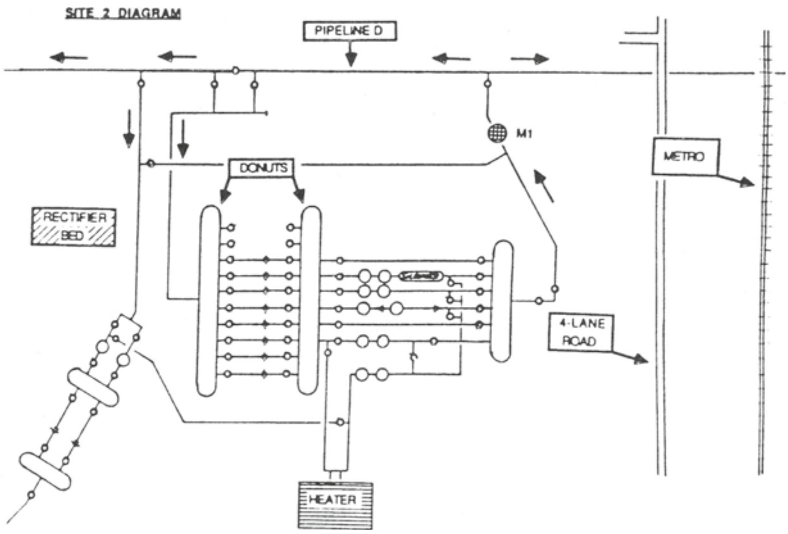

Fig 3. Map of the Test Site 2. Features: Pipeline D, metro transit line, a major road and a gas flow-rate measuring station with the rectifier bed used for CP.

RESULTS AND DISCUSSION AT TEST SITE 1

Correspondence of IR Drop and Magnetometric Measurements

Figure 4(a) shows an iR drop time record taken on the Pipeline A at the iR drop station near Location 1, which is 500' west of the metro

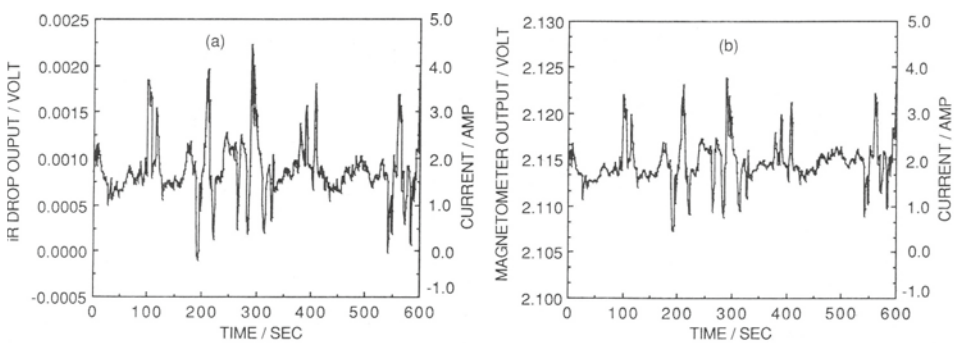

Fig. 4. Simultaneous current-time record in Location 1 at Site 1 (left of the metro location with respect to the Pipelines A & B in Figure 2), measured at (a) iR drop station and (b) by magnetometry. Y-axis description for (b) as in Figure 1.

station. The current on A at this location was simultaneously monitored magnetometrically. The result is shown in Figure 4(b). These records are completely correlated with every current pulse recorded by the iR drop technique also recorded by the magnetometer and vice versa.

The Symmetry of Current Flow from an Interfering Source

The magnetometer method has the advantage that the measurements can be made at any location. This advantage is critical to mapping distributions of on-pipe current and identifying sources of stray currents. If current from the metro is being directly injected onto the gas pipe via earth return paths, the currents on the pipelines should have opposite directionality on either side of the pipelines with respect to the metro transit line. In order to test this hypothesis, we measured the current pulses on the Pipeline A with a magnetometer 500' east of the metro line, and a second one in place 500' west of the metro line. For a 10 minute time record of the currents, there is a one-to-one correspondence between the 2 magnetometer outputs. However, the direction of the currents were not reversed, see Figures 5(a) and (b). The two magnetometers were then moved at intervals along the pipe and similar measurements were made. Reversal in the direction of the current flow was observed at the measuring station located at about 3/4 of a mile east of the transit line (Figure 2). When a location 5 meters west and 5 meters east of the gas flow measuring station was reached, the current reversal was found; the results are shown in Figures 6(a) and (b). There is a one-to-one correspondence between the current pulse amplitudes and times in this data. However, the pulses have an opposite sign which implies the currents flow in opposing directions.

The precise location of the current reversal inside the measuring station was determined by additional magnetic measurements within the station itself. The location of these tests are indicated by arrows in Figure 7, which is a part of the plan diagram of the measuring station. The directions of the arrows indicate the direction of the current and their locations correspond to the magnetometer position.

Measurements Inside the Measuring Station

The precise location of the current reversal inside the measuring station was determined by additional magnetic measurements within the

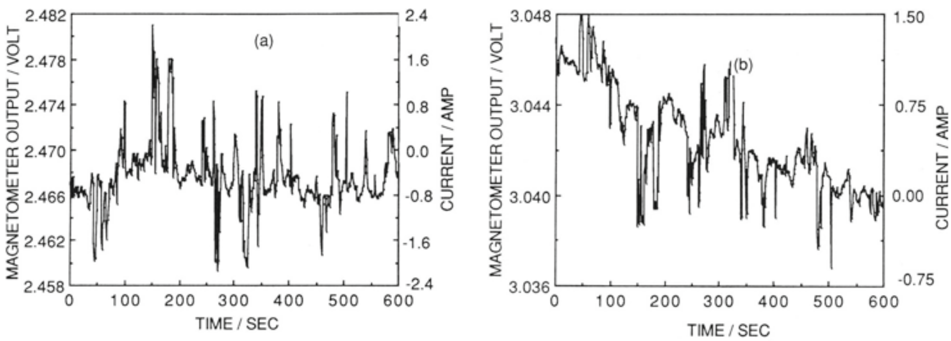

Fig. 5 Simultaneous current-time record of on-pipe current on Pipeline A made at (a) 500' left and (b) 500' right of the metro.

station itself. The location of these tests are indicated by arrows in Figure 7, which is a part of the plan diagram of the measuring station. The directions of the arrows indicate the direction of the current and their locations correspond to the magnetometer position.

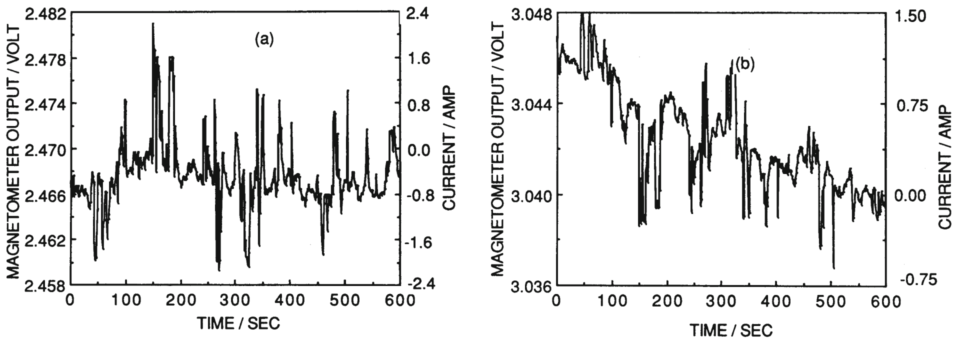

Fig. 6 Simultaneous current-time record of on-pipe current on Pipeline A (a) 5 meters left and (b) 5 meters right of the measuring station.

It may be observed from Figure 7 that the stray current pulses are fed to the transmission gas Pipelines A, B, and C through a 10" pipeline at the location M1 in the figure. It may also be seen that the currents originate from the area of the two elliptical pipes (called as "donuts", see also Figure 3). This area has three significant features: (i) The gas pipes are connected to no less than thirty sacrificial (magnesium) anodes; (ii) The main electric power supply for the station is connected to the measuring devices; (iii) The neutral of the power supply is connected to the gas pipes. Hence, the stray currents may be picked from the ground through the anodes or it may be injected from the electric power cables or the neutral. The sacrificial anodes were disconnected from the gas pipe and no major change in the stray current was observed. The electric power source was the other possibility.

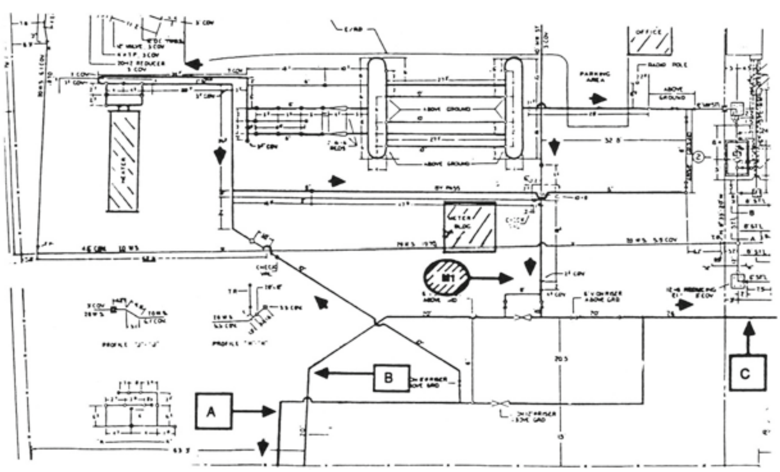

Fig. 7 Map of the flow-rate measuring station at Site 1. Arrows indicate the direction of the current as well as the location of the magnetometers during the current-time records of the on-pipe current.

The role of the electric power cables was investigated through simultaneous magnetic measurements of the currents on the 10" gas pipe, seen as M1 in Figure 7, and on the conduit containing the electric power cables and the neutral. A 10 minute recording of data from this experiment is shown in Figure 8(a) and (b), respectively. The two time records are correlated in frequency suggesting that the currents found on the gas

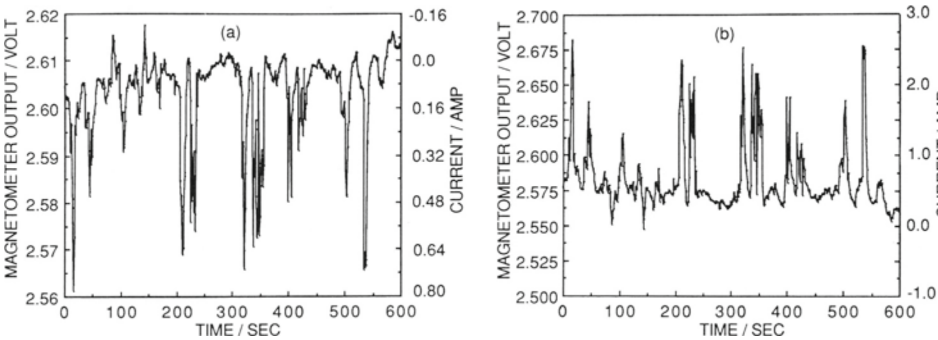

Fig. 8 Simultaneous current-time record of the on-pipe current at (a) location M1 and (b) on the power cable inside the measuring station at Site 1.

pipelines are indeed being injected from the electric power supply which includes the neutral; to test whether the neutral or the phase is the source of the stray current, the pipelines should be disconnected from the neutral during the current-time recordings. The results of this test will be published elsewhere; the results shown in Figures 5, 6, and 8 are enough to prove that the stray currents on the pipelines are not injected through any ground path, but inadvertently through the power lines.

RESULTS AND DISCUSION AT TEST SITE 2

Experiments conducted at this location are similar to those at Test Site 1. However, the high density of vehicular traffic on the road between the transit line and the measuring station creates magnetic noise which reduces the S/N obtained. Nevertheless, this magnetic noise did not prevent measurements of the on-pipe currents. Only magnetometric measurements were made at this site; iR drop measurements were not performed. The results are shown in Figure 3. The direction of the current pulses are indicated by arrows and the location correspond to the magnetometer position. At Site 1, the stray current pulses originate from the area where the pipes are connected to the pressure and flow rate measuring devices and injected on to the Pipelines A, B, and C through the 10" pipe. At Site 2 these pulses go through a 16" line connected to Pipeline D near location M1; the currents branch on to the Pipeline D with a resulting reversal of direction.

A simultaneous magnetic measurement of current on the gas pipe and the main electric power supply was made. The results were similar to the one recorded in Site 1 and shown in Figure 8; a near total correlation in frequency of the current pulses was found on the gas pipe with respect to the electric power line.

CONCLUSIONS

At both Site 1 and 2 virtually all of the stray current pulses are injected from the main electric power supply. The magnetometer has made it possible to track down the source of the stray current to a specific location, the electric power cable in these studies. There is no evidence supporting a direct transfer of current from the metro rail to the pipelines through the ground. The absence of symmetry in the direction of the stray current on either side of the metro station at Test Site 1 supports this view.

The stray current pulses found on the gas pipes originate at the metro but appear to be transferred through the electric power lines, which includes the neutral. The current pulses on the gas pipelines are correlated with metro activities: (i) a 10 minute concurrent record of on-pipe current and field leakage emanating from a transformer at the metro station (Figure 9(a,b)) show for every pulse on the metro transformer there is a current pulse on the pipe; and (ii) there is a statistical correlation of the total number of pulses (n=198) in the on-pipe current over one hour period (between 2:28 and 3:27 pm on a weekday) with the total scheduled stops and starts of trains on the metro line (n=216) assuming all the trains ran as shown on the schedule. In both cases, the correlations are only partial and cannot be considered conclusively to show that the metro is the only source of the stray current on these pipelines. The partial correlation in Figure 9 between the metro transformer current and the gas pipe current arises because several transformers serve the metro line. The currents from each transformer are coupled to the pipe and appear as the pulse sequence shown. The pulses from individual transformers are fewer in number than the total observed for the entire system.

In summary, magnetic detection of stray current distributions is a powerful new technique which offers significant advantages for pipeline inspection applications. In addition, it has potential for inspection in many other cases where access is limited by burial or by being embedded in a large fabricated structure.

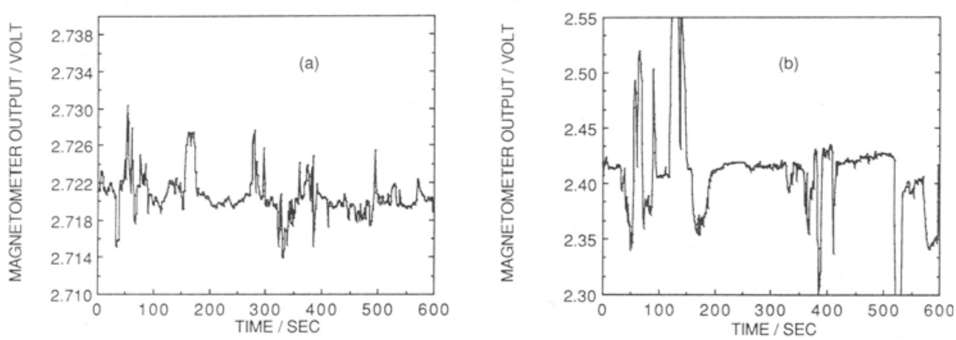

Fig. 9. Simultaneous current-time record of on-pipe current at (a) Location 1 in Site 1 and (b) near the metro transformer at the same site. The magnetometer was located at about 2 meters from the transformer. Currents are given only in terms of the magnetometer output and not calibrated in Amperes.

REFERENCES

1. Control of Pipeline Corrosion, edited by A. W. Peabody, NACE, 1977, p. 82.

Financial support by Southern California Gas Company and the New York Gas Group is acknowledged.