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# Detection and Location of Damage on Pipelines

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## DETECTION AND LOCATION OF DAMAGE ON PIPELINES

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### ABSTRACT

The INEEL has developed and successfully tested a real-time pipeline damage detection and location system. This system uses porous metal resistive traces applied to the pipe to detect and locate damage.

The porous metal resistive traces are sprayed along the length of a pipeline. The unique nature and arrangement of the traces allows locating the damage in real time along miles of pipe. This system allows pipeline operators to detect damage when and where it is occurring, and the decision to shut down a transmission pipeline can be made with actual real-time data, instead of conservative estimates from visual inspection above the area.

### INTRODUCTION

Detecting and locating damage along pipelines can be a difficult and expensive process, and there may be significant delay between the time damage occurs and the time that it is detected and located. Pipeline transmission operators have stated that their interest is in a simple, robust damage identification and location system because it will dramatically reduce the cost of detecting and locating pipeline damage.This data trace system was recently tested at the Gas Technology Institute (GTI) in Chicago, Illinois. The purpose of the test was to demonstrate how we can detect and use resistance change from the network of traces to locate the segment of pipe undergoing strain.

Figure 1 illustrates that as a section of pipe is put under strain the damage detection system indicates a change in resistance along its traces.

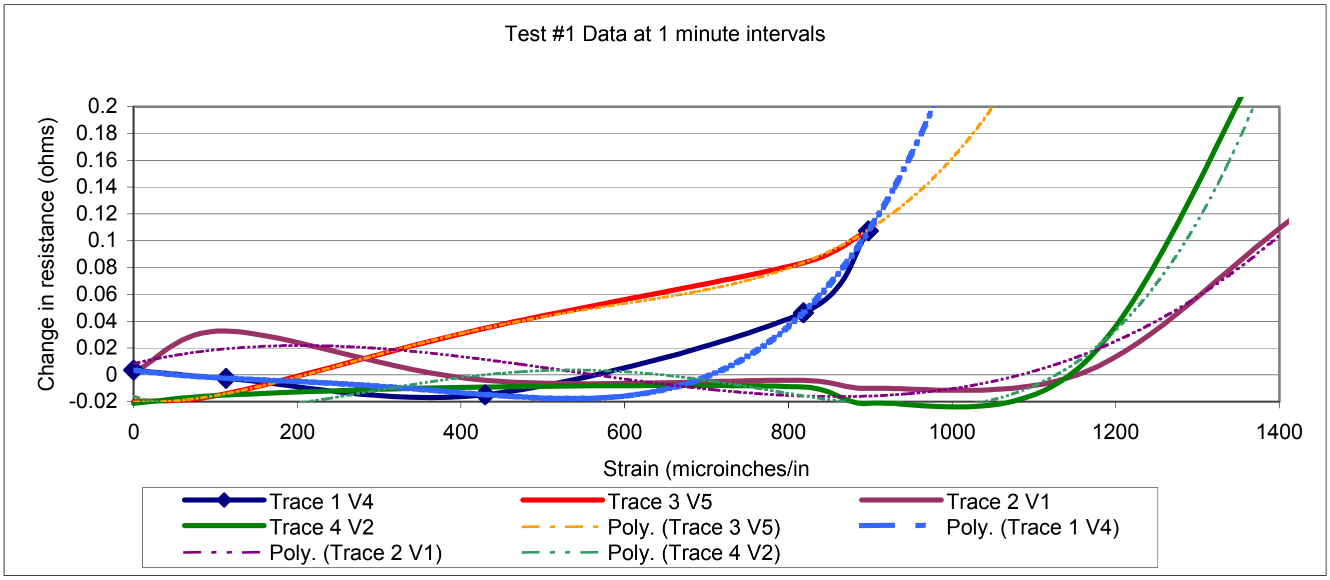

*Figure 1* ***Pipeline operators receive an immediate signal of change in resistance from the damage detection system when a section of the pipeline is put under strain.***

## PURPOSE

The data trace system detects and locates strain when and where it is occurring on a substrate. The technique employed is a network of resistive traces deposited on either the interior or exterior wall of the pipeline. The purpose of the most recent test at the Gas Technology Institute (GTI) was to demonstrate on a 50 ft long 18" diameter pipe how the resistance change from the network of traces can be detected and used to locate the segment of pipe undergoing strain. The results of the test show that this damage detection system is ready to be demonstrated on an actual pipeline system.

## BACKGROUND

A thin, porous metal stripe called the resistive trace is created when molten metal is sprayed onto a substrate. The ability of a resistive trace to detect damage is due to the unique manner in which a porous metal changes resistivity when placed under strain. The porous metal layer used in the trace shows a significant change in resistance when placed under strain. This differs from a bulk metal conductor which, when strained, maintains a constant resistivity, with the change in resistance produced by the actual change in length of the metal. The porous metal resistive trace change is not associated with a change in length, but an actual shift in the material's resistivity.

The application of the resistive trace is done using thermal spray technologies such as plasma spray or kinetic spray. Parameters of the application are tightly controlled to produce a reliable and consistent trace. The pipe is prepared by grit blasting or wire brush and a nickel aluminum bond coat is applied to the area where the traces will be sprayed. Then a insulating bond coat is applied to isolate the traces from the substrate. The traces are applied onto the insulating layer and then covered with a thin top coat of epoxy as shown in Figure 2.

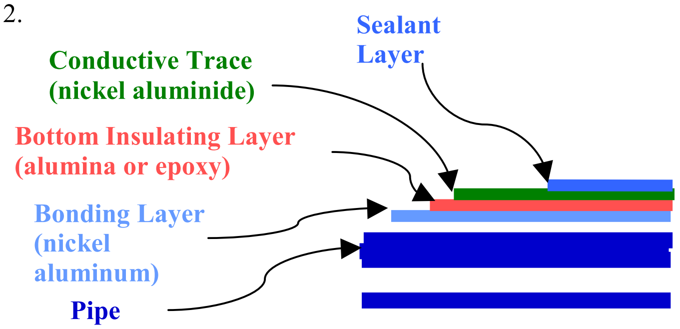

*Figure 2 Schematic of a Resistive Trace*

This system can be applied in a pipe coating facility or on location of the pipeline installation. It can be applied to the inside or the outside of the pipe.

## TRACE RESISTANCE VALUES AND CONFIGURATION

Trace resistance is controlled by changing the width and thickness of the trace, as shown in Table 2 on the next page, which presents the width and thickness of the different traces used on the GTI test. The resistive value of the trace is defined as the amount of resistance measured over a 1-ft length. Six resistive values were established for the damage detection system, and each one was assigned a value number (V1, V2, V3, V4, V5, V6). Table 2 nominal values are in ohms/ft. The same thermal spray process, using the same materials, produces each different resistive value.

The actual trace resistive values varied from the nominal value, but each trace was required to be within 20% of the nominal value at any point along the trace length. Values were measured in 2-inch increments to compare the actual value with the nominal value. The data trace system was applied to 10-ft pipe segments. The five pipe segments were welded together using standard welding procedures. The damage detection system consisted of at least five traces in parallel along the length of the pipe. The damage detection system was placed on each pipe segment on four sides of the pipe (top, bottom, both sides). Wires were used to electrically connect the traces across each pipe segment from solder pads at the end of each pipe segment.

Each of the five pipe segments had a different arrangement of five traces to allow for locating which segment was undergoing strain. The five different arrangements are shown in Table 1.

***Table 1 Different trace patterns of each pipe segment***

| | Pipe Segment 1 | Pipe Segment 2 | Pipe Segment 3 | Pipe Segment 4 | Pipe Segment 5 |
|---|---|---|---|---|---|
| Trace 1 | V1 | V1 | V1 | V4 | V5 |
| Trace 2 | V2 | V4 | V5 | V1 | V1 |
| Trace 3 | V1 | V1 | V1 | V5 | V4 |
| Trace 4 | V4 | V5 | V2 | V1 | V1 |
| Trace 5 | V1 | V1 | V1 | V2 | V4 |

## TEST CONFIGURATION

GTI fabricated a four-point bend fixture. See Figure 3. The supporting frames were 20 ft apart, and the force-inducing cylinders were centered between the frames, but 6 ft apart. The hydraulic cylinders were attached to cradles approximately 12 inches wide (along the length axis of the pipe) and 20 inches long (along the circumferential axis of the pipe). The pipe was placed into the bend fixture so that a selected segment of the pipe would be stressed into bending without placing significant stress on the other four segments of the pipe.

The pipe was rotated to align one of the four quadrants at the top of the pipe, one at the bottom, and two quadrants running along the sides. Each segment of the pipe had strain gages attached. The change in trace resistance was recorded over time, and the change in strain was recorded over time, each in separate files. Figure 4 shows the traces after one of the bend test has gone through plastic deformation.

*Table 2 Values of traces in ohms/ft and their physical dimensions*

| Value Number | Nominal (Ohms/ft) | Minimum (Ohms/ft) | Maximum (Ohms/ft) | Thickness (inches) | Width (inches) | Cross-Sectional Area (inch$^2$ × 10$^{-6}$) |
|---|---|---|---|---|---|---|
| V1 | 0.4 | 0.32 | 0.48 | 0.0042 | 0.150 | 630 |
| V2 | 0.8 | 0.64 | 0.96 | 0.0018 | 0.100 | 180 |
| V3 | 1.6 | 1.28 | 1.92 | Not used | Not used | Not used |
| V4 | 3.0 | 2.4 | 3.6 | 0.0015 | 0.080 | 120 |
| V5 | 6.4 | 5.76 | 7.04 | 0.0011 | 0.080 | 88 |
| V6 | 12.0 | 10.8 | 13.2 | Not used | Not used | Not Used |

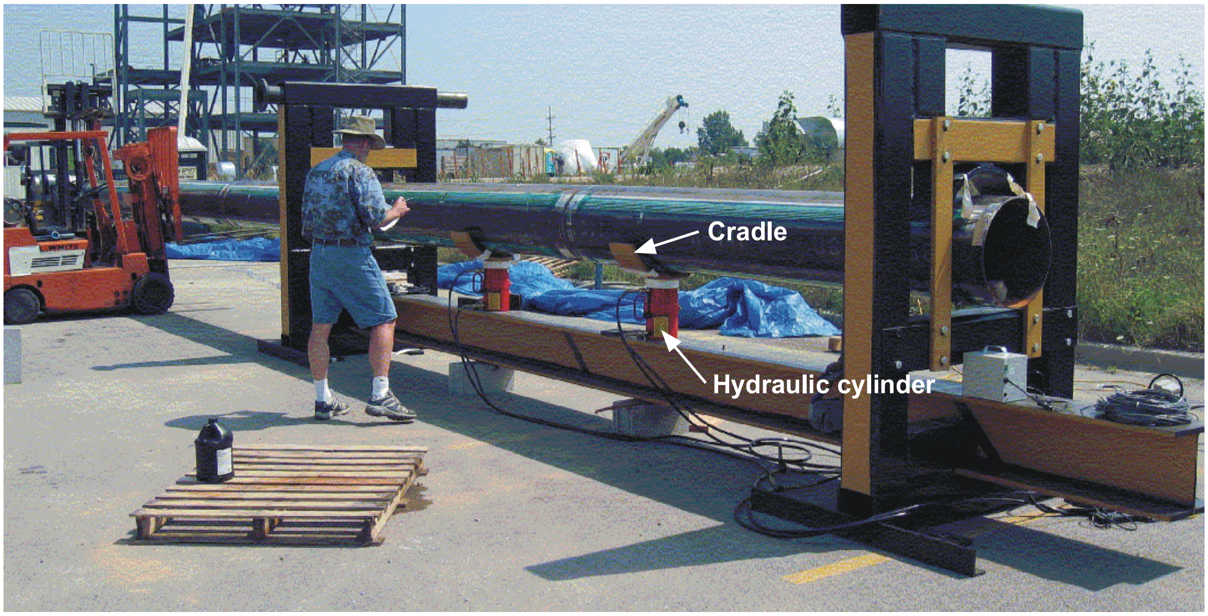

*Figure 3 Four point bend fixture for inducing strain on a 10 ft long segment of a 50 ft long pipe*

*Figure 4* ***The resistive traces after plastic deformation***

## CHANGE IN RESISTANCE OF TRACES

Figure 5 presents the raw data as an operator would observe it at a remote site. A strain diagram has been added, with its values on the right side y-axis. An operator in the field would not have access to the supplemental strain data. At low values of strain, there is a range of noise that could be filtered out. But as the traces begin to show changes greater than 0.05 ohms from the baseline condition, there is a trend above the noise level. An operator would begin to realize that an event was occurring along the pipeline.

As the change in total trace resistance increases above 0.05 ohms to 0.10 ohms, the trace is responding to the strain occurring on the pipe segment. The total range of variance level is chosen to be 0.05 ohms. That level would be the minimum level for an operator to start reacting to possible damage on the pipe.

Traces with different resistive values reacted to the strain with a similar pattern, but at different levels of strain. The trace with V1 values (0.4 ohms/ft) and V2 values (0.8 ohms/ft) reacted 60 to 120 seconds later than trace 1, V4 value (3 ohms/ft), or trace 3, V5 value (6.2 ohms/ft).

Data traces with higher resistance values show an increase sooner, with respect to the amount of strain. Trace 3, with V5 values (6.2 ohms/ft), shows a 0.05-ohm change in resistance at 750 microinches/in. Trace 1, with V4 values (3.0 ohm/ft), shows a 0.05-ohm change in resistance at 825 microinches/in., while trace 5, with V2 values (0.8 ohm/ft), shows a 0.05-ohm change in resistance at 1200 microinches/in. Trace 2, with V1 values (0.40 ohm/ ft), shows a 0.05-ohm change in resistance at 1200 microinches/in. The operator would have first seen the rising trendlines of trace 3 and then trace 1, and would know that trace 3 had the highest resistance value in the segment under strain, followed by trace 1, and would use that information to begin to locate the damaged segment. Five traces are considered sufficient for locating damage on a 20 mile pipeline to within 80 ft.

Figure 6 shows the change in resistance with the data taken over minutes instead of seconds so the noise has been removed. The change in resistance is shown through plastic deformation of the pipe as shown by the strain measurement. Trace 4 with V5 values (6.2 ohms/ft) is the first to respond and increases rapidly. Trace 2 with V4 values (3 ohms/ft) is next trace to respond. The same data is shown in Figure 6 but at a much smaller scale so the initial response of trace 4 and trace 2 can be seen.

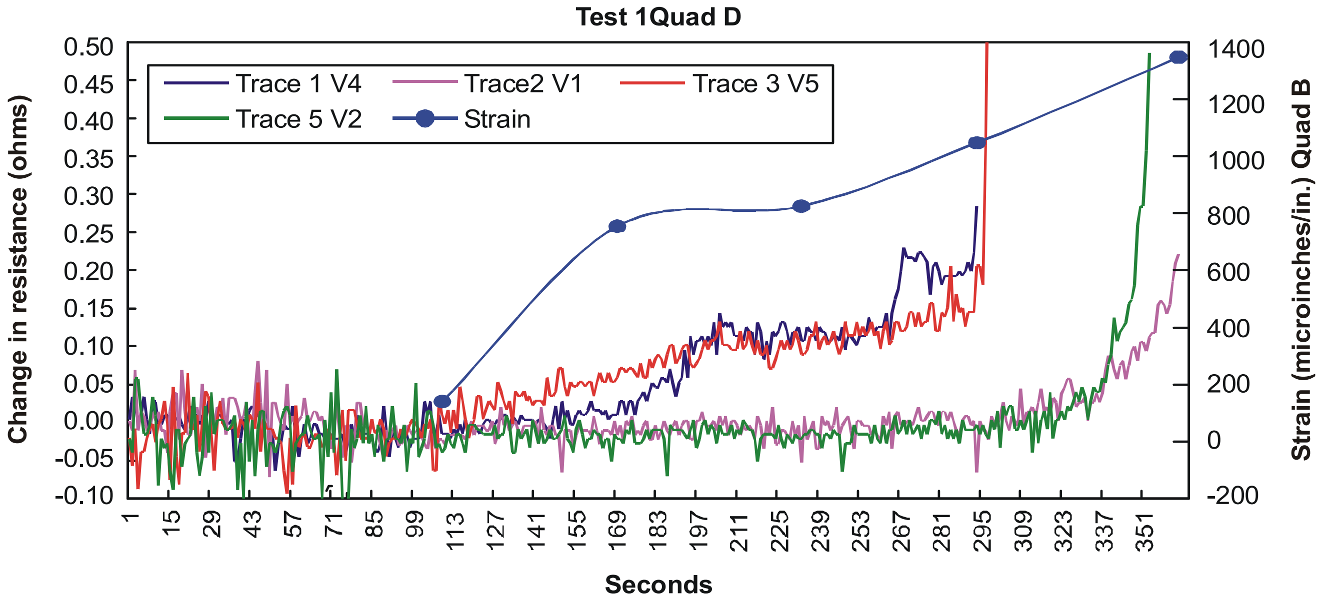

*Figure 5 Strain is shown on the right axis and change in resistance of four different resistive values are shown on the left axis*

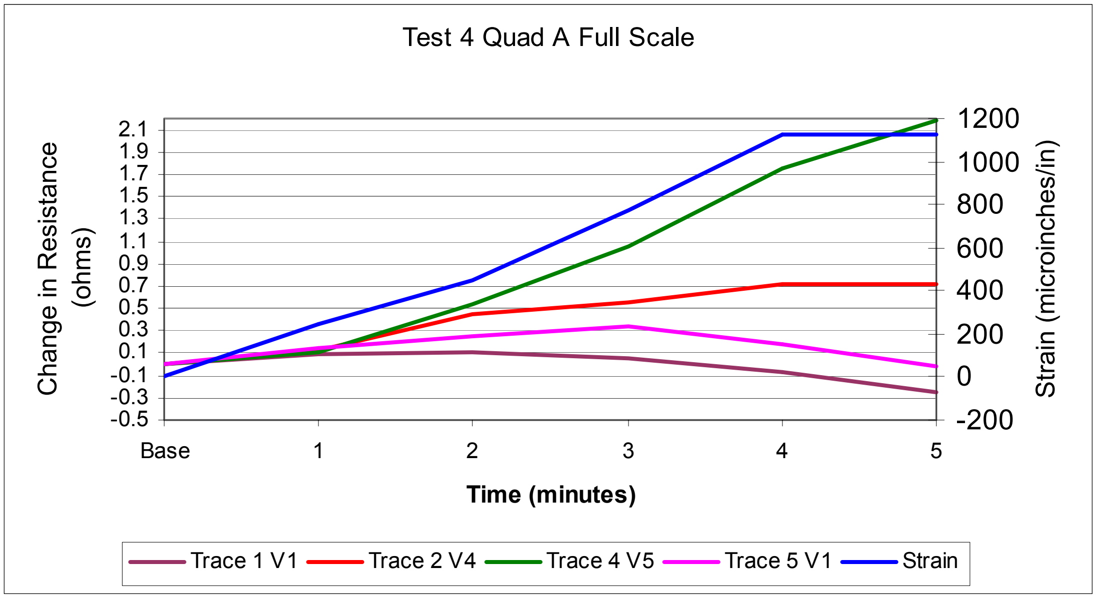

*Figure 6 Full change in resistance up through plastic deformation*

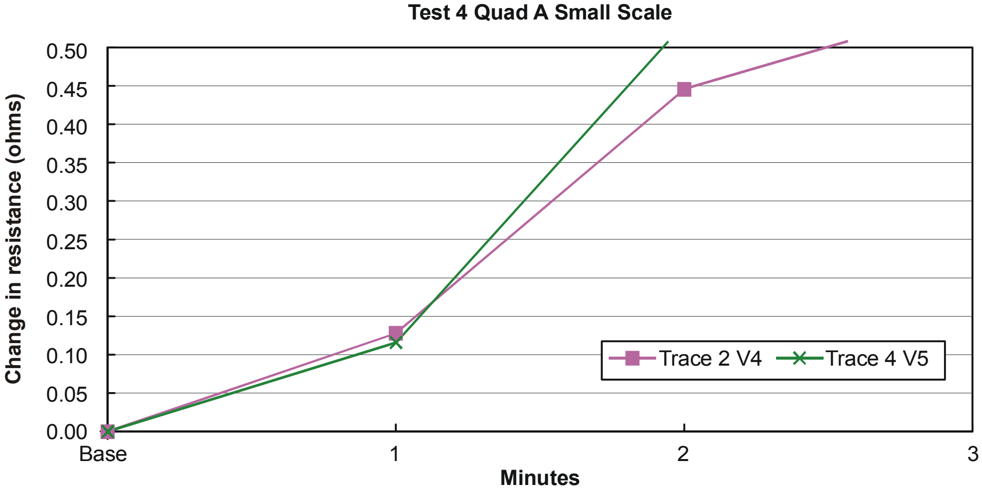

*Figure 7 Small scale of change in resistance for the first two minutes.*

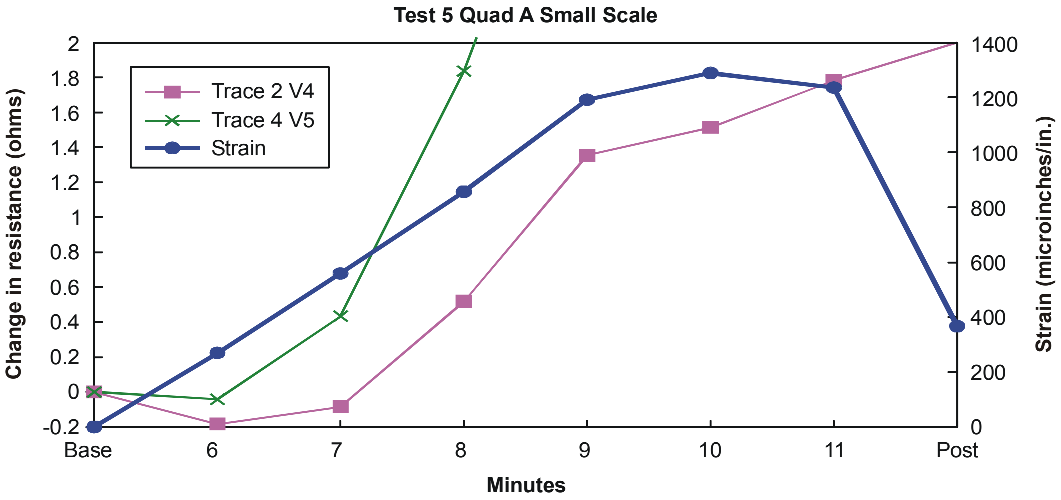

*Figure 8 When the test is done again on the same pipe segment there is greater sensitivity to strain*

In Figure 7, trace 4 and trace 2 responses are identical at low levels of strain. At 300 microinches/in. the trace 4 response begins to be greater than trace 2.

In Figure 8, the test has been repeated on the same pipe segment. Trace 4 and trace2 responses occur at slightly lower strain and show a greater change in resistance.

## STRAIN VS CHANGE IN RESISTANCE

Analysis was done on the correspondence between the change in resistance of a trace as a function of strain. The initial resistive value of the trace is a function of its width and thickness. While the relationship appears to be a fourth order polynomial, the response of the resistive trace to strain appears to be different for each resistive value. The higher the initial resistive value, the faster the trace increases in resistance to strain. This behavior will allow location of the damage along a pipeline.

Characterization of the response needs to be done to a wide range of resistive values. Further research is occurring on the cross-sectional change in the porous metal. The heterogeneous mixture of conductive metal, oxides and voids within the trace are assumed to rearrange under strain changing the electron path through the conductive metal as it crosses boundaries between the individual metal splats.

## PRODUCTION DESIGN

Further work has been done on the method of applying the resistive traces to the pipe. Many aspects of the process have been optimized to allow the damage detection system to be applied at a pipe coating facility at a very small cost/ft of pipe.

## CONCLUSION

The INEEL has developed and successfully tested a real-time pipeline damage detection and location system. Axial strain was induced on the pipe creating tension on the top of the pipe and compression on the bottom of the pipe. Detection of the strain on the pipe segment was immediate. The detection occurs in both the elastic deformation and plastic deformation phases. The signal response from the high resistance value traces occurs at much lower levels of strain than was expected. This sensitivity allows for the detection system to respond to a strain field occurring along the circumference of the pipe between the areas where the damage detection system is located

Examination after testing showed the traces to have disbonded from the pipe within the alumina layer. In some instances even though the traces were no longer connected to the pipe they were still capable of conducting an electrical signal. This is considered the preferable failure mode over the traces breaking along the conductive traces. Future improvements to the damage detection system include using epoxy or plastic for the insulating layer. The relative bond strengths of the epoxy to the steel and the conductive traces to the epoxy will be characterized and controlled to keep the insulating layer as the preferred layer for adhesive failure.

Location of the pipe segment undergoing damage is possible using the unique responses of each resistive value. The order in which the traces respond allows the software to select the damaged pipe segment.

The tolerance range of each trace’s resistance value is approximately +/- 10% over each pipe segment. It is important to the data trace system locating function for each value to be distinct and easily identified. The five values chosen for the data trace system do not overlap each other. This low level of variance is due to many process controls and techniques developed for the data trace system.

Individual trace resistance analysis would not have been possible if the tolerance range in the traces had been greater than the 10% band. The low tolerances allowed the distinct curves of each value to be apparent, facilitating location of damaged pipe segments. The high resistance trace of each particular segment reacts first, with a change in resistance at very low levels of strain. The next highest resistance trace reacts next, with a slightly different slope. The variability in resistance along the length of a particular trace does not prevent the unique curve of the baseline resistance from being distinct. Trace values V2 and V1 are both low resistance traces with very similar behavior, but can still be distinguished from each other.

While this noise can always be filtered out by the software, it is significantly lower than the change in trace values, and is not considered an impediment to detection and location analysis.

## ACKNOWLEDGMENTS

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