Combination MFL/Deformation Inspections of Small-Diameter Unpiggable Pipelines.

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Abstract

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(MFL)/Deformation inspection tools used to inspect small diameter, previously unpiggable, pipelines.

Small diameter pipelines have been historically very difficult to inspect with In-line Inspection (ILI) tools. Small diameter pipelines are challenging because they leave ILI system designers little space to fit the required system components of an ILI tool. In addition, many small diameter pipelines were designed and built without any consideration for ILI tool passage, including but not limited to, tight radius bend fittings and no launchers or receivers installed on the pipeline.

Recent advancements in microprocessor computational power, memory density, sensor technology, engineering design/modelling software, and rare earth magnetic technology have allowed an inspection system to be developed to inspect these small diameter pipelines.

This paper will describe the design parameters used to develop this new system. Several case studies will be presented showing real-world application of this new system.

Introduction

The purpose of this paper is to describe a new family of combination Magnetic Flux Leakage (MFL)/Deformation inspection tools used to inspect small diameter, previously unpiggable, pipelines.

Small diameter pipelines have been historically very difficult to inspect with In-line Inspection (ILI) tools. Small diameter pipelines are challenging because they leave ILI system designers little space to fit the required system components of an ILI tool. In addition, many small diameter pipelines were designed and built without any consideration for ILI tool passage, including but not limited to, tight radius bend fittings and no launchers or receivers installed on the pipeline. Additionally, when a pipeline contains different thicknesses of pipe and/or fittings, these variations add restrictions to the bore of the pipeline. These restrictions to the bore as a percentage of the total bore is much higher than in larger diameter pipelines. For example, in a 3" pipeline, going from schedule 10, with a wall thickness of 0.120" to an extra heavy wall thickness of 0.3" would equate to a bore restriction of 12%. In a 30" pipeline this transition would only be 1.3%.

Recent advancements in microprocessor computational power, memory density, sensor technology, engineering design/modelling software, and rare earth magnetic technology have allowed an inspection system to be developed to inspect these small diameter pipelines.

This paper will describe the design parameters used to develop this new system. Three case studies will also be discussed showing real-world applications of this new system.

ILI System Development

Several design parameters were selected and applied to the new inspection tools. First and foremost, the inspection tools would use the MFL technique to detect metal loss in the pipelines. The MFL technique is not new to inspection of pipelines or to non-destructive testing. The MFL technique was first used on an ILI tool in the 1960's, over 50 years ago[i]. Second, the tools would have deformation technology to measure the bore of the pipe and detect geometric anomalies in the pipe wall with a tolerance of +/- 1%. Third, the tools could be configured to be bi-directional. This would allow the tools to access pipelines from a single point of entry. Forth, the tools would need to traverse 1.5d bends. Fifth, the tools would need tight circumferential sensor spacing, twice the density of other ILI tools. Sixth, the tools would need a tight axial sample distance, twice the sample rate of other ILI tools.

These parameters created two major challenges for the design. First, induce a magnetic field into the pipe wall with adequate strength to detect metal loss and still pass a 1.5d bend in the pipeline. Second, create a data acquisition system that was small enough to fit into the pipeline bore yet have enough capability and capacity to process and record data collected by the tool.

The design process was started in 2010. The design of the tool's magnetic section was refined using finite element software that models magnetic fields. The advancement of finite element software has simplified the design of the magnetic circuit on the tool used to induce a magnetic field into the pipe wall[ii]. The design of the tool's electronics required the use of state-of-the-art microprocessors, memory chips and magnetic sensors.

The design process began with a 3" inspection tool. A 3" tool was chosen due to the limited quantity of pipelines smaller than 3" and the physical limitations in generating a magnetic field in pipelines smaller than 3".

The first commercial 3" inspection was conducted in the fall of 2015. It was a success and afforded the opportunity to compare the results of the inspection to an ultrasonic inspection that was also conducted in the same pipeline. The MFL/Deformation tool and the ultrasonic tool saw the same dents and almost all the dent depths detected by both tools were within 1% of each other. The metal loss detection was vastly different. The ultrasonic tool reported 1 metal loss anomaly, and the MFL/Deformation tool reported 27 metal loss anomalies, with two of them being 70% deep. Defect verification was done by the pipeline operator and the metal loss calls from the MFL/Deformation tool were located and verified.

Case Study #1, 4" Line with Bore Restrictions

KMAX was contacted by a pipeline operator. The operator has a 4" butane pipeline that is 10 miles long. The pipeline had never been inspected by a metal loss ILI tool. The operator wanted to run an ILI tool through the line to determine the line condition.

The pipeline operator contracted another ILI company to run a caliper tool through the pipeline to determine the minimum bore of the pipe. The ILI company reported several locations that had bore restrictions down to 3.6". The ILI company could not inspect the pipeline with their MFL tool due to the bore restrictions.

The pipeline operator reached out to 6 different ILI vendors to see if they could inspect the pipeline. All 6 vendors declined to inspect the pipeline due to the bore restriction, or the butane product.

The minimum bore of KMAX's 4" tool is 3.6". KMAX and the pipeline operator began a series of discussions to determine if the 4" tool could successfully pass through the pipeline.

The pipeline was built in the 1960's with schedule 40 pipe. Later in 1980's the pipeline was modified by the installation of two above ground valves. The above ground valves were designed and installed with schedule 80 pipe and fittings. Forty-five (45) degree, schedule 80 bends were used to bring the pipe out of the ground and turn the pipe horizontal above ground.

The 3.6" restrictions detected by the geometry tool were associated with the girth welds of the 45-degree, schedule 80 bends and the adjacent pipe or fittings.

Figure 1 Location of 3.6" Restriction--Sch. 80 Bend and Tee (Note the High/Low Weld)

The pipeline was a critical line for the operator. Taking the pipeline out of service with a stuck inspection tool would have a major impact on the operator and the downstream facility. The pipeline operator wanted a very high confidence level that the inspection tool would not stick in the pipeline.

In order to obtain a high level of assurance that the inspection tool would not become stuck in the pipeline the pipeline operator wanted to do full scale testing by duplicating the line configuration of the above ground valve locations.

A testing facility was contracted to create the same pipe configuration as the valve sites in the pipeline. This included a section of straight schedule 80 pipe, a 45-degree 3d bend, a short section of schedule 80 pipe, another 45-degree, 3d bend, and another section of straight pipe.

The difficult part of designing the test pipe configuration was figuring out how to simulate the restrictions that were detected in the pipeline. Several ideas were discussed, but the best idea was to place flanges at the ends of the 45-degree, 3d bend. A steel ring could then be inserted in between the flanges to simulate the restrictions. This design would allow the rings to be changed out expeditiously to test different diameters of restriction. It would also allow rings to be fabricated to a very high tolerance level. The rings were designed with full circumferential restrictions. Four different ring sizes were chosen. The inside ring diameters ranged from 3.7" to 3.55". A total of five flanges where installed in the test pipe.

Figure 2 Test Pipe Showing Launcher and Receiver, Bends, and Pump

Figure 3 Test Pipe with Flanges on the End of Bends

Figure 3 Flange with Restriction Ring

Figure 4 Restrictive Rings Installed Between Flanges

A requirement for the simulation test pipe was that the ILI tool testing would be done by propelling the tool with water. The test pipe had to contain a launcher and receiver and fittings to pump water through the pipe. A positive displacement pump was also required to be able to provide the pressure and flow rates needed to test the tool. Pressure sensors were also required to measure the pressure required to move the ILI tool through the test pipe.

Over a four-day period, 21 tests were conducted in the test pipe. The first test was conducted with no rings in the system. The largest diameter ring (3.7") was next to be inserted in the system. Smaller rings were then introduced working down to the 3.55" diameter rings. Several tests were run with the 3.55" rings. The tool was stopped at various positions in the test pipe. The tool was stopped prior to the first bend, in the middle of the first bend, between bends and in the middle of the second bend.

The test system was fitted with a pressure monitoring system to measure the pressure it took to push the tool through the test pipe. Each test was monitored to detect pressure spikes when stopping and starting the ILI tool. Figures 5 and 6 show the pressure profile of the ILI tool in the test pipe with 3.55" diameter rings. Figure 5 is without stopping, and Figure 6 is with stopping the ILI tool in each of the two bends. The maximum pressure detected was 163 psi. There is a section of schedule 40 pipe near the end of the test pipe. The pressure to push the tool through the schedule 40 pipe was less than 30 psi.

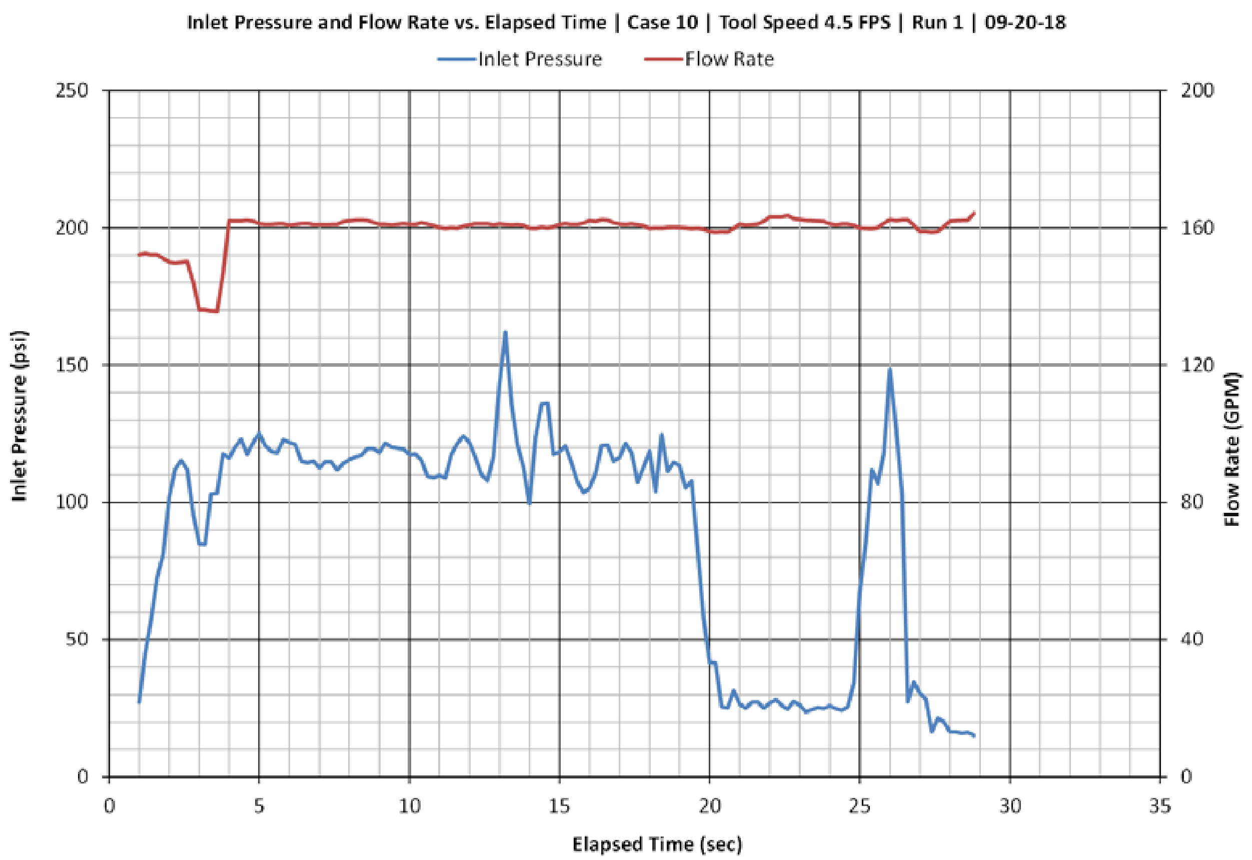

Figure 5 Pressure and Flow of Test Pipe with 3.55 Diameter Rings, with No Stopping

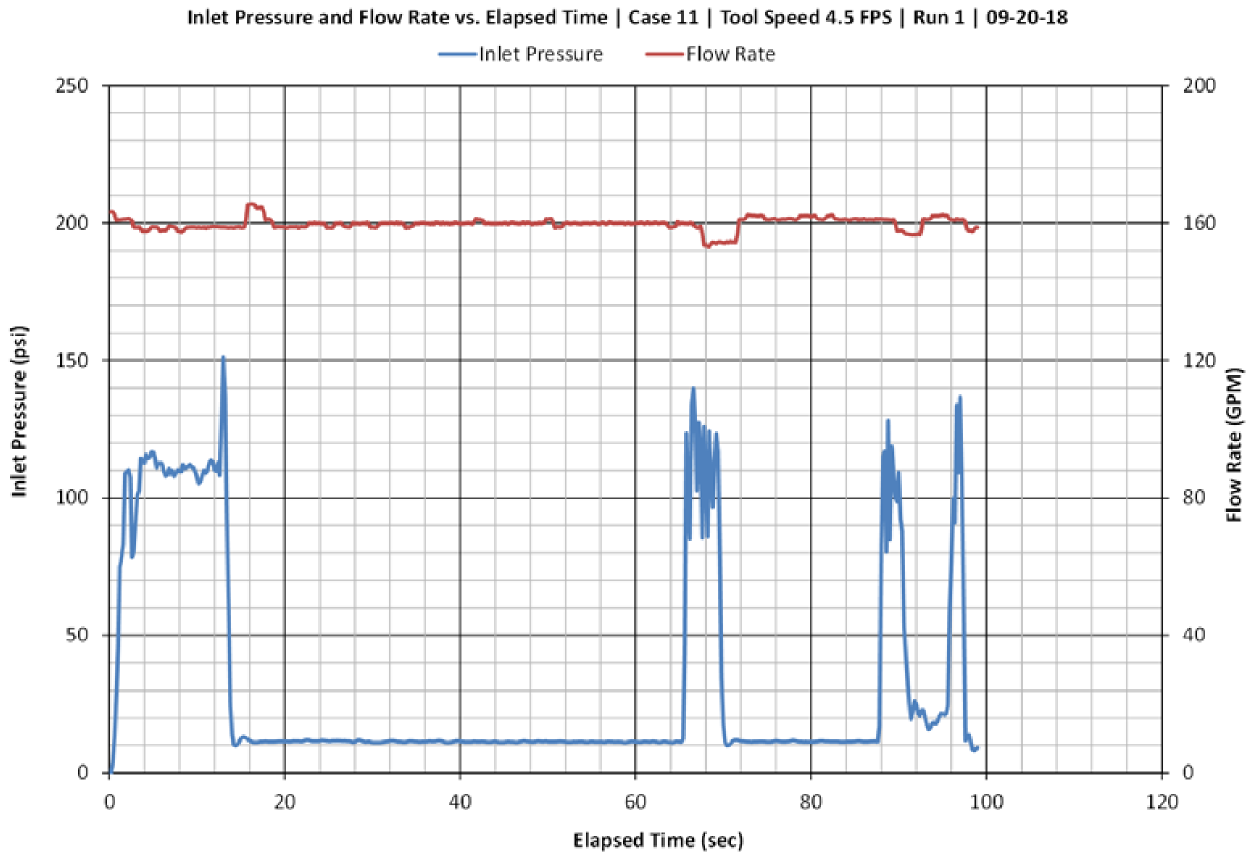

Figure 6 Pressure and Flow of Test Pipe with 3.55 Diameter Rings, with Two Stops

Throughout all the test scenarios the ILI tool never stuck in the restrictions. At the conclusion of the testing phase the operator had a very high confidence level the ILI tool would not stick in their pipeline and recommended that we move forward with the inspection of the 4", 10-mile-long pipeline.

The pipeline operator still wanted to be prepared for the possibility of sticking a tool in their line. They came up with a plan to have "one calls" made for both valve sites and have tested replacement pipe on hand prior to running the ILI tool to minimize down time on the pipeline should the ILI tool get stuck in the line.


Figure 7 One Call Stakes at Valve Site

The pipeline operator created a calibration spool of 4" schedule 40 pipe that contained both internal and external metal loss features as well as dents. The spool was brought to the launcher and prior to launching the ILI tool, the pipeline operator pulled the ILI tool through the spool with a strap using a pickup truck. This spool would allow the operator to validate the performance of the ILI tool.


Figure 8 Calibration Spool of 4" Sch. 40 Pipe

The ILI tool was run through the pipeline. Both valve sites were closely monitored to make sure the ILI tool made it through the restrictions. The tool passed both valve sites with a constant speed and never stopped or slowed down.

When the ILI tool was removed from the receiver, it was covered in a lot of ferrous debris from the pipeline. The pipe had been cleaned with foam and brush cleaning pigs but had never had a magnetic cleaning pig run through the pipeline. The tool was downloaded, and the data evaluated. There were several MFL sensors that were damaged during the ILI tool run. A review of the data also revealed that the background magnetic level of the ILI tool diminished over the length of the pipeline due to the ferrous debris collecting on the ILI tool.

Because the damaged sensors and sensor coverage did not meet the customer's acceptance criteria for ILI tools, a rerun was necessary. A rerun was rescheduled and performed. The ILI tool was closely monitored through all valve locations. The tool passed through these all sections with no difficulty.

Case Study #2, 3" Line with 1.5d Bend

KMAX was contacted about inspecting a 3", 2-mile, Natural Gas pipeline. The line had never been inspected by an inspection tool. The nominal wall thickness was .156 ERW pipe, with potentially thicker wall thicknesses in the pipeline. The pipeline was constructed in 1962. There was no launcher or receiver facilities installed on the pipeline. The line had a 1.5d, 45deg, schedule 40 bend installed. The pipeline normally operated at a low pressure of around 100 psi.

Figure 9 A confirmed 1.5d, 45 deg. bend in the pipeline.

Because of the low pressure it was determined that the pipeline would have to be taken out of service to perform the inspection, and the inspection tool would be pushed through the line using water.

The line was taken out of service and temporary launchers and receivers where installed on the pipeline. The line had never had any pigs run through it since 1962, so a cleaning/gauge pig was planned prior to running the KMAX inspection tool.

A pump truck was used to provide water and a pump to propel the ILI tool through the line. The pump truck was configured with a centrifugal pump, a pressure gauge, but no flow meter.

The first cleaning pass of the cleaning/gauge pig was conducted. The pig got stuck in the nominal pipe of the receiver after passing through the receiver valve. The receiver was disassembled, and the cleaning/gauge pig was removed from the pipe with a winch. The cleaning/gauge pig got stuck on a heavy weld in heavy wall pipe in the receiver. The pump truck, which was capable of providing 100 PSI, could not produce enough pressure to move the cleaning/gauge pig past the weld. There were two options to remedy this situation. Get a pump that would provide higher pressure or reconfigure the pipe in the receiver. It was decided to reconfigure the pipe at the receiver, due to time constraints to get the line back into service.

The cleaning/gauge pig had ferrous debris on it after the first pass, so it was decided to run the pig a second time to get the line clean.

Figure 10 KMAX Cleaning/Gauge Pig with Magnets, Brush, Gauge Plate, and 22hz transmitter

Figure 11 Debris on Magnets of Cleaning Pig

After the cleaning of the pipeline the ILI tool was run through the pipeline. The ILI tool was launched, and the tool left the trap, and went through the value. The pressure on the pump truck indicated a pressure of 110 psi. The pump operator assumed that there was water flowing from the pump truck into the pipeline. After about 15 minutes of operation, the operator noticed that the water level in the tank was not dropping. There was no flow meter in the system to indicate that water was flowing in the pipeline. A system check of the pipeline configuration revealed that the valve at the receiver had not been opened. Once this valve was opened, water started flowing through the pipeline. The ILI tool passed through the 1.5d bend with no pressure spikes and with out stopping.

The overall success of the inspection is attributed to preplanning all aspects of the inspection from installing temporary traps, cleaning, inspection, and putting the line back in service. The line was out of service for 3 days to complete the inspection. There are some lessons to be learned here. The biggest issue was having the wrong pump truck for the job. A truck with a positive displacement pump vs a centrifugal pump would have been a better setup for this job. Also having a flow meter inline would have helped as well.

Case Study #3, 4" Line with Heavy Wall Fittings

KMAX was contacted about inspecting a 4", 16-mile, Natural Gas Liquid (NGL) pipeline. The line had never been successfully inspected by an inspection tool. An attempt to inspect the line in the past had caused a stuck inspection tool. The nominal wall thickness was .237, with potentially thicker wall thicknesses in the pipeline.

The inspection was planned in stages. The 1st stage would be running a cleaning/gauge pig through the line. If there was no damage to the gauge plate, the 2nd stage would be running the KMAX MFL/Deformation combo tool through the line. If there was damage to the gauge plate, then KMAX would run the stand along deformation tool to locate areas in the pipeline that where a concern.

The KMAX cleaning/gauge tool was run through the line. The gauge plate came back with bent tabs. The diameter of the gauge tool was 3.25" and the damage was full circumferential.

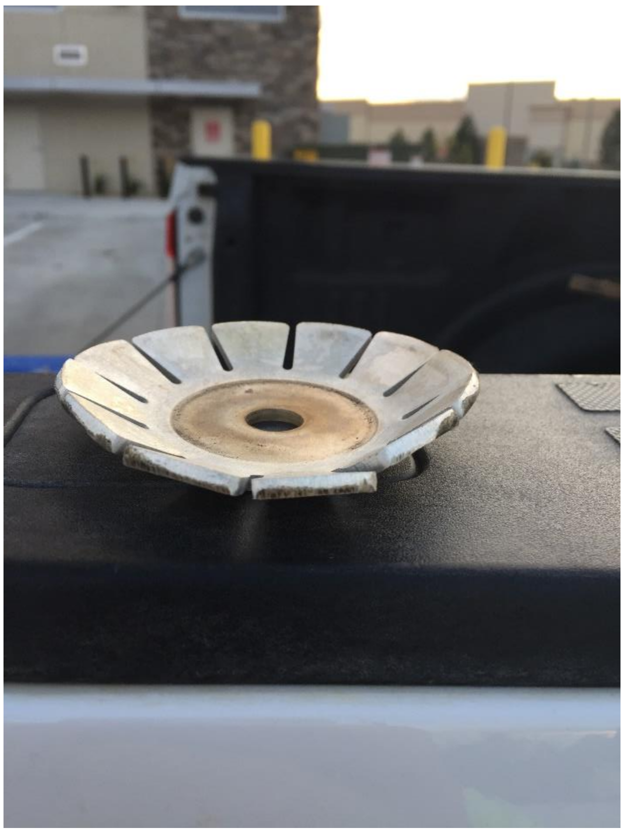

Figure 12 The Gauge Plate Showing Damage Around the Full Circumference of the Plate

KMAX then decided to run the KMAX Deformation tool to locate the restrictions in the pipeline. The Deformation tool was run through the pipeline with no issues.

Once the data from the Deformation tool was evaluated it showed that the pipeline had extra heavy fittings at the launcher, at the 3 above ground valve settings, and at the receiver.

Location	Minimum Bore
Launcher	3.45” in Tee
Above Ground Valve Setting	3.43” in Tee
Above Ground Valve Setting	3.23” in Tee
Above Ground Valve Setting	3.48” in Tee
Receiver	3.36” in Tee

Figure 13 Above Ground Valve Setting with Heavy Wall Tee

In addition, there were 4 dents detected that were above the pipeline operator’s 0.5% reporting threshold for dents. 1 dent was 12.2%, and the other 3 were less than 1%. The 12.2% dent was an ovality in a joint of pipe that was 41 feet in length.

The pipeline operator decided that the number of repairs necessary to be able to run the KMAX MFL tool was too extensive and decided to hydro test the pipeline. The operator did investigate the 12.2% dent. The dent was caused when a fibreoptic cable was installed parallel to the 4” pipeline. A boring machine was used to install the cable and during the process damaged the 4” pipeline. This section of pipe had to be replaced due to the damage.

Figure 13 4" pipeline with Fibreoptic Cables in Same Right-Of-Way

Figure 14 4" Pipeline with an ID of 4.5", Showing an Ovality of 1"

This case study helps identify some of the issues that are common with fittings that are installed on small diameter pipelines. Extra Heavy tees were used, with a wall thickness as thick as .635" for a 4" pipeline. The tees installed where rated for 4,529psi, while the established MAOP on the line was 1,440psi. While these fittings may be strong, they exclude any ability to run ILI tools, and they can restrict the throughput of the pipeline.

Pipeline Operators or designers are cautioned about using heavy wall fittings on small diameter pipelines. There is no minimum bore requirements for fittings. ASME B16.9 states "Bore diameters away from the ends are not specified. If special flow path requirements are needed, the bore dimensions shall be specified by the purchaser."[iii]

Lessons learned

There are several lessons learned and to be shared. First, these small diameter pipelines are difficult to inspect. In 2018, over 50% of the lines inspected by the KMAX system were unable to be inspected by other ILI vendors' tools. In small diameter tools, there is not a lot of room to protect sensors from the pipeline environment. While every effort is made to make a system that is robust, sensor failure occurs. Inspecting many pipeline segments with varying hurdles with this system has allowed the ILI tool design to evolve and improve. The evolution of the sensor system has continually been optimized to withstand tight bends and large restrictions commonly found in small diameter pipelines.

Most of the inspections with the KMAX system have been in pipelines that have never had an ILI tool run through the pipeline. Cleaning the pipeline is very important, especially if the line has never had a magnetic cleaning pig or MFL tool run through the pipeline. Ferris debris can remain inside a pipeline segment even after running a foam or cup pig through the pipeline segment.

Our experience with inspecting these pipelines compelled KMAX to develop its own cleaning pig. The goal was to develop a multi-bodied cleaning tool that would contain brushes, magnetics and gauge pig to detect restrictions in the line. We feel that this type of cleaning tool is import to the successful inspection of these small diameter pipelines.

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