MFL Inspection of Small Diameter, Previously Unpiggable, Pipelines-- Lessons Learned.

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Abstract

Small diameter pipelines have been historically very difficult to inspect with In-line Inspection (ILI) tools, especially using the MFL technique. 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. For example, many small diameter pipelines have tight radius elbow fittings and no launchers or receivers installed. 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 several case studies and lessons learned about doing 1st time, MFL inspections of previously unpiggable, small diameter, pipelines.

Introduction

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 elbow fittings, heavy wall tees and no launchers or receivers installed on the pipeline.

Since 2015, KMAX Inspection has been focused on inspecting 3" to 6" pipelines. 59% of our inspections have been first time inspections, meaning it is the first time that an ILI tool has been run through the pipeline.

The purpose of this paper is to share with the industry some lessons learn on inspecting small diameter pipelines using the MFL technique.

Small Diameter Pipelines

Small diameter pipe is used to transport low volumes of product a short distance. Small diameter pipe is often used in a gathering field to move product from a well to a storage facility. Small diameter pipe is also used in refineries and plants to move low volumes of product short distances. Many of these pipelines were built with no thought of ever running inspection tools through the pipeline.

With the progress of governmental regulation, many of these small diameter lines are being pulled into regulations that require the pipeline to be inspected. This creates a need to evaluate the pipeline to see if it is possible to run an ILI tool through the line without modification, and if modification is needed, how to modify the line in a cost-effective manner.

Small diameter pipe itself can easily be inspected by various non-destructive evaluation (NDE) techniques. Once small diameter pipe is installed into a pipeline, with valves, bends, and fittings, then the NDE methods to inspect the pipe reduce based on what choices a pipeline engineer made when designing and building the pipeline, the modifications made the pipeline after it was installed, and the environmental exposure the pipeline has been subjected to after it was placed in service.

ILI Technologies for Small Diameter Pipelines.

There are two families of ILI technology that can be used to inspect small diameter pipelines. The first family is ultrasonic ILI tools, and the second family is MFL ILI tools. There are strengths and weakness for both systems, so a quick discussion about each family of ILI technology could be helpful. This is not meant to be a complete comparison of the technologies, but a high level comparison.

Ultrasonic

The ultrasonic family of ILI tools uses the NDT technique of generating an ultrasonic sound wave from a piezoelectric crystal. The wave enters the pipe wall and then continues to travel until it is reflected by the opposite pipe wall, or an anomaly within the pipe. The reflected wave then exits the pipe wall and is detected by a piezoelectric crystal. If the wave is sent perpendicular to the pipe wall it can detect the wall thickness of the pipe wall, along with both internal or external metal loss. If the wave is sent at a non-perpendicular angle to the pipe wall, the wave will enter the pipe wall and reflect off cracks within the pipe wall. Let's review some of the pros and cons of using the ultrasonic technique in small diameter pipelines.

PROS

1. Direct Measurement. The ultrasonic technique is a direct measurement of the pipe wall based on a "time of flight" calculation of the wave inside the pipe wall.
2. Sensor Indirect Contact. The ultrasonic sensor does not have to ride on the surface of the pipe wall. This allows ultrasonic systems to be able to navigate restrictions and tight bends found in pipelines.

CONS

1. Pipeline Product. Must be run in a fluid. Won't work in NGL or natural gas lines
2. Line Cleanliness. Line must be clean and free of debris
3. Cost. Usually more expensive than MFL technology
4. Pipe Curvature. Small diameter pipe has a curvature that can diminish the ultrasonic signal
5. Thin Wall. Ultrasonic technology can struggle in 3" and 4" sch. 10 pipe.

MFL

The magnetic flux leakage (MFL) family of ILI tools induce a strong magnetic field into the pipe wall with very strong, rare earth, permanent magnets. The magnetic field on the inside surface of the pipe wall is monitored with magnetic sensors to look for changes in the magnetic field.

PROS

1. Feature Detection. MFL tools do a great job of detecting features in a pipeline such as welds, laminations, tees, casings, puddle welds, and metal loss.
2. Metal Loss Detection. MFL tools will see more metal loss anomalies than ultrasonic technology
3. Works in Liquid and Gas. MFL technology will work in both liquid and gas pipelines.
4. Cost. Usually cheaper than ultrasonic technology

CONS

1. Quantification of Metal Loss. MFL is an indirect measurement as thus does not size defects accurately, thus a tolerance is applied to defect sizing.
2. Line Geometry. MFL tools have magnets and magnets take space, thus MFL tools cannot pass tight restrictions in the pipe such as dents, sharp elbows or other bore restrictions.
3. Wall Thickness. MFL tools have limitations on inducing magnetic fields in thick pipe. 3" and 4" MFL tools can work in pipe schedules up to sch. 40. 6" MFL tools can work in pipe schedules up to sch. 80.

Evaluate the Pipeline for the Chosen ILI Technology

To complete a 1st time inspection of a pipeline, the pipeline must be evaluated to determine the feasibility of running the chosen ILI tool and what modifications would need to be made to allow passage of an ILI tool. Here is some of the information about a pipeline that needs to be gathered:

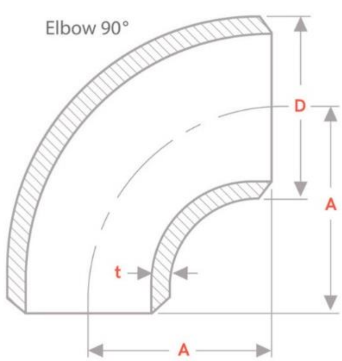
Pipe Wall Thickness

The maximum and minimum wall thickness needs to be determined and evaluated. Sometimes there are pipeline records that can be used to determine this. If the pipeline is old, there might not be good records of what wall thickness of pipe was used to fabricate and repair the pipeline over its history. If the records are incomplete, information needs to be gathered. This can be achieved by taking manual wall thickness measurements in all above ground piping with a handheld ultrasonic wall thickness measurement device. While this method is not a complete inspection of the pipeline, it allows an easy to obtain sample of what wall thicknesses are in the pipeline. The best and most complete way to obtain the wall thicknesses that is in the pipeline is to run a geometry/deformation ILI tool through the pipeline.

Fittings

There are two areas to focus on when evaluating fittings in a pipeline. The 1st area of focus is on forged elbows. If the pipeline contains forged elbows, the bend radius of the fittings needs to be determined, along with the wall thickness of the elbow. The 2nd area of focus is on forged tees. Most pipelines have at least two forged tees, one at the launcher and one at the receiver. The wall thickness of each forged tee should also be determined.

Small diameter forged elbows have a radius that is calculated on the nominal OD of the pipe size, and not the actual OD of the pipe. For example, a 3" pipe has an OD of 3.5", but the elbow radius is calculated using the nominal OD of 3". This pattern holds for all pipe sizes below 14".



D	A
3.5"	4.5" (3" * 1.5)
4.5"	6" (4" * 1.5)
6.625"	9" (6" * 1.5)
12.75"	18" (12" * 1.5)
14"	21" (14" * 1.5)

Figure 1--Elbow Radius is Calculated Using the Nominal Diameter of the Pipe Instead of the Actual Diameter for all Pipe Diameters Below 14"

Figure 2 Above Ground Valve Setting with Heavy Wall Tee

Figure 3--Heavy Weld Penetration at Transition from Straight Pipe to 1.5d Bend


Figure 4--Location of a 3.6" Restriction in a 4" pipe--Sch. 80 Bend and Tee (Note the High/Low Weld)

If the pipeline documentation does not contain complete records, you can evaluate all above ground elbow and tees wall thickness with a handheld ultrasonic wall thickness tool and evaluate the bend radius with a tape measure. This will provide a sample of the fittings that were used to construct the pipeline.

Minimum Bore

For safe passage of an inspection tool, the minimum bore of the pipeline should be determined. This can be accomplished by running a gauge plate pig through the pipeline, or by running a geometry/deformation tool through the pipeline. Minimum bore in the pipeline is usually caused by heavy wall fittings, elbows, pipe, dents or heavy weld penetration.

Traps

If the pipeline has a launcher and receiver, it might need to be modified for the ILI tool. On the launcher, the most important dimension is the length of the oversized pipe. The oversized section of the launcher must be longer than the ILI tool, unless there is a way to pull the ILI tool into the nominal pipe of the launcher.

On the receiver, the most important dimension is the length of nominal size pipe after the receiver valve. Most modern ILI tools drive from the front, so the length of nominal pipe must be longer than the ILI tool to be able to pull the tool past the receiver valve.

Figure 5--Launcher Site with No Trap Installed

Figure 6--Launcher with Short Oversized Section and No Way to Push Product Behind the ILI Tool

Figure 7--Temporary Extension to Launcher Trap with Piping to Push Product Behind the ILI Tool

Pipeline Product and Speed During the ILI inspection.

The pipeline must be evaluated to make sure the product and flow rate of the pipeline is compatible with the chosen ILI tool and the flow rate. If not, then the pipeline might have to be evacuated and another product used to propel the ILI tool. For example, if the line contained NGL and the chosen tool was an ultrasonic ILI tool, the NGL must be removed from the pipeline and water, or another suitable fluid must be used to propel the ILI tool through the line. Another example would be a low-pressure gas line that does not have enough pressure or flow to run an MFL tool, might have to have nitrogen introduced to create enough pressure and flow to run the MFL tool.

Dents

Dents in the pipeline can be caused during the construction of the pipeline, by construction equipment operating near the pipeline, or by ground movement. Potential dents could possibly cause an ILI tool to become stuck in the pipeline. The possibility of dents in the pipeline should be identified by a gauge plate pig, or and ILI geometry/deformation tool.

Figure 8 4" Pipe with an OD of 4.5", Showing an Ovality of 1"

Figure 9--Dent in a 3" pipe

Internal Debris

The pipeline should be clear of internal debris, ferrous material, or paraffin. If the pipeline has never had a cleaning pig with a magnet run through the pipeline, then plan on running this type of cleaning tool to remove ferrous material that could be in the pipeline.


Figure 10--Magnetic Cleaning Pig with Ferrous Debris

Case Study #1, 4" Line with tee

A 4" crude oil gathering line was going to be inspected with an MFL ILI tool. This was the 1st inspection of this pipeline by an ILI tool. Prior to running the MFL/DEFORMATION combo tool in the line, a gauge/cleaning pig was run in the pipeline.

The gauge/cleaning pig was run in the pipeline with no issues. Figures 11-14 show the condition of the pig after being run through the pipeline. The gauge plate had 2 tabs slightly bent, as shown in Figure 14. After a discussion with the pipeline operator, it was decided that although the gauge plate had bent tabs, that the bore of the pipe would probably be able to pass the MFL ILI tool.

Figure 11--Drive Section of Cleaning Tool with Magnet After Being Run in the Pipeline

Figure 12--Brush Section of Cleaning Tool After Being Run in the Pipeline

Figure 13--Gauge Plate Section of Cleaning Tool with Bent Tabs

Figure 14--Gauge Plate with Bent Tabs

When the ILI tool was run through the pipeline, the MFL ILI tool became stuck, and product was bypassing the ILI tool. The location of the ILI tool was determined by locating the last above-ground marker (AGM) location the tool passed by, and then using a handheld location device, a technician walked along the pipeline right of way and was able to locate the ILI by detecting the 22hz transmitter located within the ILI tool.

The pipeline was excavated at this location, and it was determined that a tee fitting was used as an elbow. The ILI tool was not able to navigate through the tee and became stuck in the tee. The line had to be evacuated and the ILI tool removed at this location.

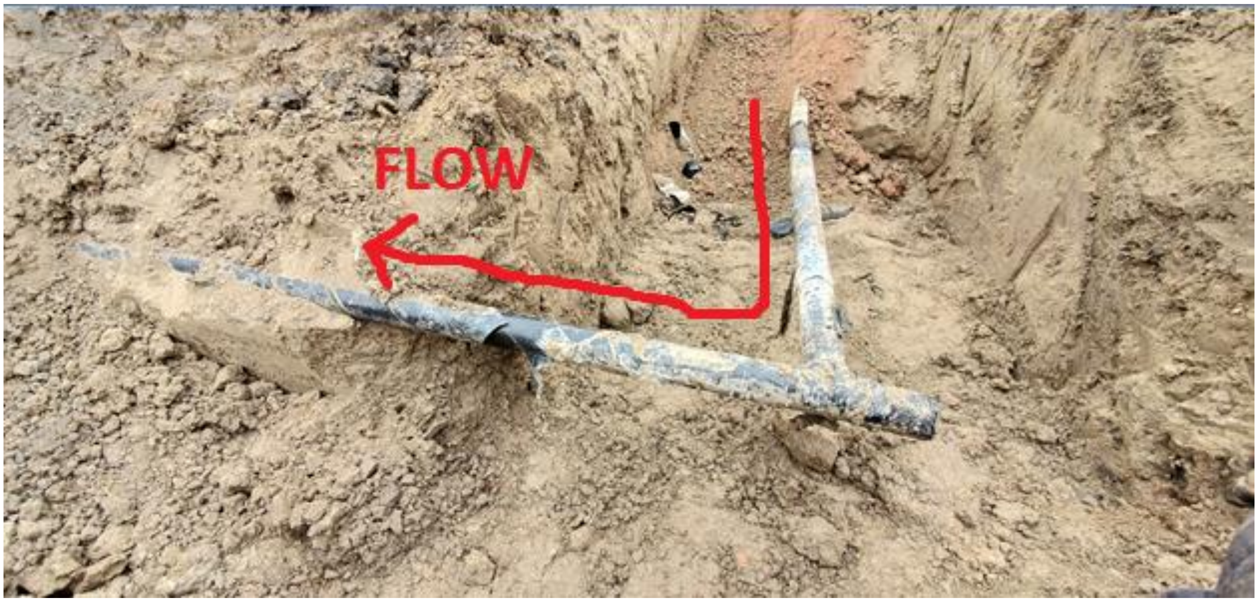


Figure 15--Tee in Pipeline, Used as a 90 Degree Elbow

So how could this situation be avoided?

1. At some point in time this pipeline was modified. The crew doing the modification should have never been allowed to use a tee as an elbow.
2. Sometimes after running a gauge pig through pipeline, the results are "shades of grey" and not black and white. A calculated risk needs to be made on running an ILI tool, or running a geometry/deformation ILI tool to investigate further.
3. If the choice would have been to run a geometry/deformation tool, the same result would have occurred with an ILI tool stuck in the pipeline.

Case Study # 2, 6" Line with back-to-back 1.5d heavy wall tees with heavy weld penetration

A 6" butane pipeline was constructed in the 1960s with back-to-back, 90 degree, 1.5d, sch. 80, elbows. The operator desired to run an ILI tool through the pipeline to detect metal loss. In preparation for running a metal loss ILI tool through the pipeline, the operator ran a geometry/deformation ILI tool through the pipeline. The geometry/deformation ILI tool reported that there was heavy weld penetration on the elbows with a minimum bore of 5.1".

The operator reached out to several ILI vendors to see if their ILI tools could inspect the pipeline. The only ILI solution provided was to run an ultrasonic ILI tool. The ultrasonic ILI solution would require the operator to remove the butane from the pipeline and flood the pipeline with water. This solution would be very expensive and inconvenient for the operator. The operator reached out to KMAX for a solution. After evaluating the pipeline configuration, it was determined that KMAX's 6" MFL ILI tool might be able to complete the inspection. The minimum bore of KMAX's 6" MFL ILI tool is 5.125". KMAX proposed to the operator that a gauge plate pig be run through the pipeline with a gauge plate diameter of 5.2".

KMAX provided the operator a 6" gage plate pig, which has a magnetic drive section and a gauge plate section with a 5.2" plate (reported minimum ID for the line is 5.1"). This tool would also employ a 22-Hz transmitter to aid in locating the tool should it become lodged.

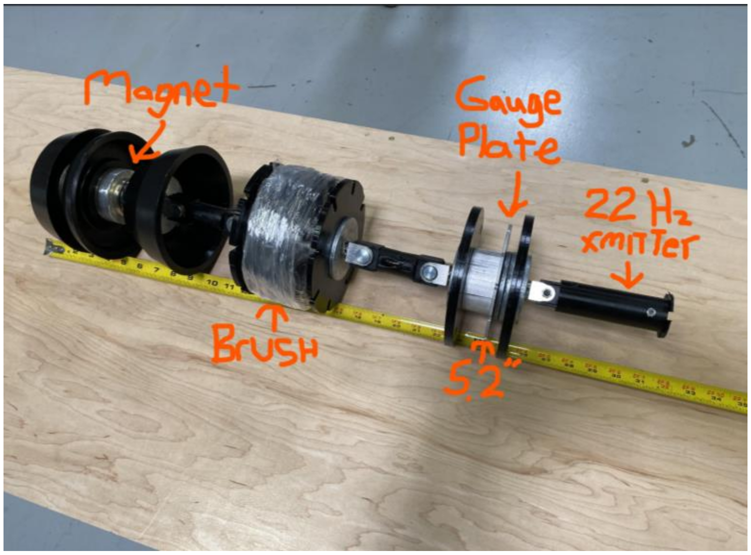


Figure 16--6" Gauge Pig Configuration

The gauge pig was run through the pipeline without issues. The results of the gauge pig were that there were no deflections of the gauge plate tabs. There was also some light ferrous material collected on the magnet.


Figure 17--Condition of the 6" Gauge Pig After Being Run Through The Pipeline

The KMAX MFL/DEFORMATION/IMU combo ILI tool was then run through the pipeline. The tool was able to collect data and produce a report on the condition of the pipeline.

Case Study #3, 3" pipeline with internal corrosion.

An operator of a 3" pipeline built in the 1960's wanted to inspect the pipeline with a metal loss ILI tool for the 1st time. The operator modified the launcher and receiver traps to accommodate ILI tools. KMAX provided the operator a 3" gauge pig that included magnets, brushes, a gauge plate and a 22hz transmitter. The pipeline contained propylene. The operator chose to remove the propylene from the pipeline and propel the gauge pig with nitrogen.

The gauge pig was run through the pipeline and became stuck in the pipeline. The operator started to investigate the location and cause of the stuck gauge pig. During that investigation, it was determined that there was a very heavy tee (wall thickness of 22.3 mm or 0.877") near the receiver. This section of the receiver was just rebuilt to get the line ready for an ILI metal loss inspection. This heavy wall tee was used as part of this reconstruction. Clearly no one was thinking about obstructions that might hang up inspection tools when this tee was installed into the new receiver configuration.

Figure 18--3" Heavy Wall Tee With Wall Thickness Up To 22.3mm(0.877")

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With the tee removed, and the gauge pig removed from the pipeline, another gauge pig was run through the pipeline. The gauge pig had a lot of ferrous debris attached to the magnets on the pig, and the polyurethane cups and disks where extremely worn. Additional cleaning pigs where run

through the line to remove the ferrous debris from the pipeline. The amount of debris on the pig magnet did not diminish. Eventually, 30 cleaning tools were put through the pipeline before the ferrous debris diminished. Approximately 20 pounds of debris was removed from the 3" pipeline that was only 3,500' in length.

The MFL ILI tool was run through the pipeline and a good inspection was obtained. The results of the inspection showed significant internal corrosion along the bottom of the pipe.

Figure 19--Magnetic Cleaning Pig Results, with Ferrous Debris Attached to the Magnet

Figure 20--Magnetic Cleaning Pig Results, with Ferrous Debris Attached to the Magnet

Figure 21--Final Magnet with Reduced Ferrous Debris

Lessons learned

There are several lessons learned and to be shared. First, these small diameter pipelines are difficult to inspect. Many 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 elbows 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.

Tees are very problematic in 3" and 4" pipelines. Tees are not inspected for bore diameter before being installed into pipelines, and many heavy wall tees are used in these pipelines. Don't select fittings that are a higher schedule of wall thickness than the nominal wall thickness of the pipeline. Also remember that 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."[i]

References

[i] ASME. B16.9 – 2007: Factory-Made Wrought Buttwelding Fittings, Section 6.2.2. New York, New York: America