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What in-line technologies work best for condition assessment of pipelines, and why.

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ABSTRACT

Direct Condition Assessment (DCA) of pipelines in Water, Waste Water, Oil or Gas service is growing in popularity due to the fact that Asset Managers need to know the condition of their pipelines, in detail, in order to maintain them and extend their life. Knowing which DCA Tool is best for a given type of pipeline is an important step in selecting the best technology. This paper discusses the attributes of In-line Inspection (ILI) Tools that utilize Remote Field Technology (RFT), Ultrasonic (UT), Electro-Magnetic Acoustic Technology (EMAT) and Magnetic Flux Leakage (MFL) Tools and discusses the strengths and limitations of each.

Keywords: Direct Condition Assessment (DCA); MFL; Ultrasonic (UT); EMAT: Remote Field (RFT); In-Line Inspection Tools; Pipeline Integrity

BACKGROUND

Budgeted dollars for pipe replacement in North America, for potable water and waste water pipelines, are so low that they only allow the annual replacement of typically less than 1% of the existing installed length[1]. At the same time, our aging infrastructure is failing at an accelerated rate. A study done by Utah State University[2] concluded that $1trillion is needed for municipal pipe replacement over the next two decades.

The cost of replacing pipelines varies widely, depending on pipe size and location within city streets; however, the cost of Direct Condition Assessment (DCA) is usually less than 5% of replacement cost[3]. Therefore, asset managers can tangibly benefit by performing a thorough DCA on a pipeline that is being considered for replacement or re-hab, before putting together a budget. Good decisions result from having good information. This hypothesis is true so long as there are no other compelling reasons for replacing a pipeline (such as a need to increase C-factor or overall capacity to an area, re-paving a major artery, or increasing reliability in instances where a pipeline "just can't fail"). For pipelines that are simply aging and/or leak frequency is increasing, the value of DCA presents a compelling cost-benefit argument.

WHAT IS DCA?

Direct Condition Assessment (DCA) is the process of determining the actual condition of a pipeline using direct measurement means. These measurement means can include sample removal, ultrasonic thickness measurements, CCTV, Sonar, Laser, external scanning Tools and In-Line Inspection Tools. None of these technologies tell the whole story about pipe condition, and the owner may choose to run more than one or two of them to obtain the most complete information. The objective of taking these direct physical measurements is to determine the remaining structural wall thickness ("strength") of a pipe, and to impute its remaining life. To accomplish these measurements in a meaningful way, the full circumference and axial length of the pipe must be interrogated with high-resolution sensors. With such sensors, even small areas of local degradation can be detected and quantified.

Carbon steel, cast-iron and ductile-iron pipes typically corrode in local areas when external coatings or wrap breaks down, allowing ground water to contact the pipe. Electric current flowing between the pipe and soil is a small galvanic cell which over time reduces the metal to its oxide. In the case of cast and ductile-iron the corrosion process is known as graphitic corrosion. As the iron is reduced, a matrix of graphite is left behind. The graphite still has some structural strength, until it reaches a critical size when an event such as frost heave, water hammer, earthquake or traffic vibrations can cause the graphite plug to fail, resulting in a leak or catastrophic break.

Detecting these areas of corrosion pitting allows the DCA contractor to create a thickness profile of the pipeline for its full length and allows an asset manager to rank the pipe according to its current condition and to calculate its useful remaining life from the data and other inputs. Knowing the exact location and severity of the local corrosion pits provides an opportunity to proactively repair them (by using an external clamp or a small, localized replacement), or to choose a rehabilitation technique such as a liner. Both options are considerably less expensive than wholesale replacement of a pipeline, and in most instances, it is likely that a significant percentage of the pipeline length will be found in serviceable condition where no money has to be spent on it at all for many years.

Pipelines are also subject to internal corrosion and erosion, depending on water chemistry and abrasive product such as sand in waste water lines; however, for municipal water pipelines, the predominant failure mode is from external (soil side) corrosion.

Oil and gas (O&G) pipelines tend to be very well protected from soil side corrosion through polyethylene coatings; and the predominant failure mechanism is from internal pitting due to the corrosive liquids carried by the O&G pipelines. One exception is the area around welds where typically a "shrink sleeve" is installed. If the installation is not correct, the pipeline can fail when ground water contacts the pipe under the shrink sleeve.

Fig-1: typical galvanic corrosion cells in ductile or cast-iron pipe

Fig-2: corrosion failure under improperly applied shrink sleeve on steel pipeline

In-Line Inspection Tools (ILI tools) can provide the precision to detect small, deep local pits over long lengths of buried pipelines. This is the most common inspection method for O&G pipelines. ILI Tools are sent through the pipeline, usually after moderate cleaning and bore-proofing, with the flow of the product inside the pipeline. Long lengths of pipeline can be inspected with the ILI Tool in "free swimming" mode, or shorter lengths in "tethered" mode. In the case of municipal pipelines, the pipe must usually be excavated and taken out of service for a short period of time. The pipe is cut into and a launch barrel is installed. The Tool is introduced into the pipe through this launch barrel.

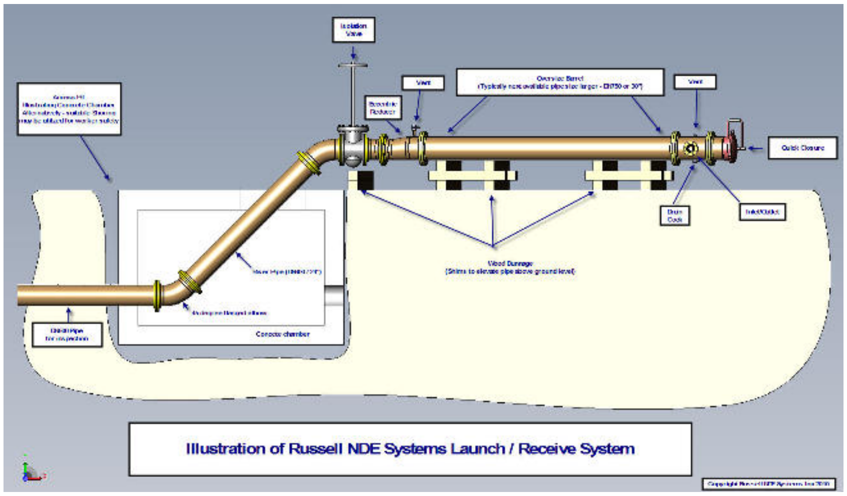

Fig-3: Typical launcher or Receiver for Municipal application (chamber)

Note: water from nearby hydrant is connected to the launcher to propel the Tool

Fig-4: Typical launch barrel for O&G application

The ILI Tools can employ one of several kinds of Non-Destructive Test techniques such as:

- Magnetic Flux Leakage (MFL) (Fig-6) below
- Remote Field Technology (RFT) (Fig-5 below)
- Ultra-sonic Technology (U.T.) (Fig-7 below)
- Electro-Magnetic Acoustic Technology (EMAT)

- Acoustic
- Sonar
- Laser
- CCTV

The last three of these in-line inspection techniques generally provide information about the inside of the pipe. They do not measure remaining wall thickness in metal pipelines, and therefore are only partial condition assessment tools. Likewise, acoustic tools simply listen for leaks and have no predictive value for future leaks. They also do not measure local remaining wall thickness.

Of the remaining four techniques, all of them measure remaining wall thickness and can detect internal and external pits and cracks. Only Remote Field (RFT) has the ability to measure the remaining wall thickness in all three materials (steel, cast and ductile-iron) when they also have thick liners such as cement mortar or polyethylene (P.E.); internal debris; internal scale or tubercles. The other three techniques (MFL, EMAT and U.T.) require a relatively clean and smooth inner surface in order to couple their sensors to the pipe to measure the remaining wall thickness. MFL Tools can sometimes measure through thin liners and coatings so long as they are smooth. Most RFT Tools have all sensors contained within metal pressure housings that do not require contact with the pipe. Neither do they require magnetic saturation (as do MFL Tools) or liquid couplant (as do UT Tools).

Fig-5: Typical RFT Tool (courtesy PICA Corp)

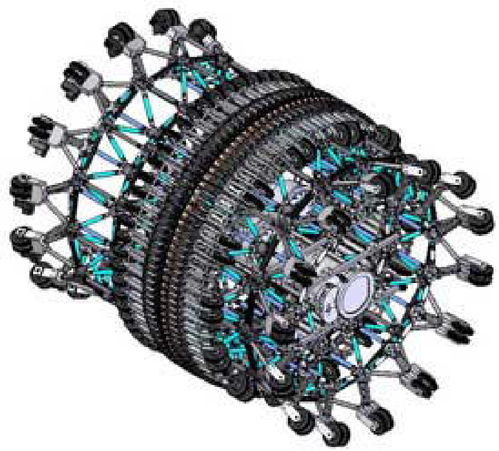

Fig-6: Typical MFL Tool (courtesy Pure Technologies)

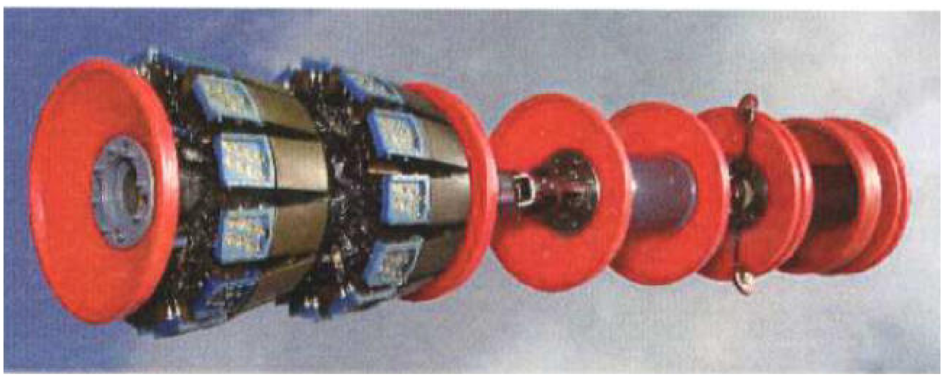

Fig-7: Typical Ultrasonic Tool (courtesy Weatherford Oilfield)

Fundamentals of electromagnetic techniques

MFL, RFT and EMAT Tools all rely on voltages being generated in coils or solid state devices such as hall sensors. The voltages generated are dependent on the following factors:

- The relative magnitude of the ***change*** of the magnetic field
- The ***speed*** that the coil or hall device passes through a static magnetic field, or
- The ***rate of change*** of a changing (AC) magnetic field (i.e. Frequency)
- The ***volume*** of the metal loss that causes the change in the magnetic field.
- The ***proximity*** of the sensing device to the source of the change in magnetic field

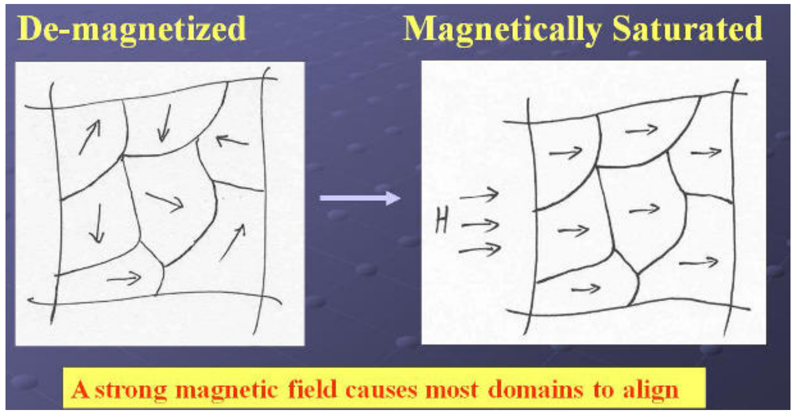

Fig-8: Depiction of magnetic domains within a ferrous metal

Random magnetic domains (left) and magnetically saturated state (right)

The illustration above shows the random nature of magnetic domains in ferrous metals (illustrated on the left). MFL technology requires that the domains be aligned (illustrated on right). This is accomplished through the application of a strong DC magnetic field (usually through the use of permanent magnets) For MFL the relative magnitude of the signal is related to the strength of the permanent magnets used, the thickness of the material under test and the *proximity* of the sensing devices to the inside of the pipe. If the material is relatively thin and the magnet relatively strong, and the proximity is very close then the material may become "saturated" with magnetic flux lines, making MFL technology work very well..

Saturation occurs when the addition of more magnetic force makes no change to the magnetic domains in the material. All magnetic domains point in the same direction and the relative permeability of the material is reduced to a value close to unity.

Effective MFL inspection relies on magnetic saturation of the ferrous material in order to overcome magnetic permeability variations that are inherent in steel, cast and ductile iron. It is increasingly difficult to saturate the material if the magnet is at some distance from the material.

EMAT and **RFT** techniques also rely on the rate of change of a magnetic field; however, the field is produced **not** by permanent magnets alone, but by coils carrying alternating current. For EMAT and RFT, saturation of the material is usually not attempted; hence magnetic permeability (measurement of variations in the random magnetic domains mentioned above) is measured along with wall thickness. Magnetic permeability is greatly affected by stress and strain in the material, and therefore, the measurement of magnetic permeability can be quite valuable. Localized stress in a high pressure pipeline can lead to failures due to stress-corrosion cracking and/or fatigue cracking. Localized stress can be found on pipelines that have moved due to earth slippage (such as on side hills and in earthquake zones), and pipes that have leaked and caused a sink hole (where the pipe becomes un-supported from below and acts like a bridge). Another common source of local stress is where concrete anchor blocks have sunk. Anchor blocks are commonly used in O&G pipelines near every riser where the pipe comes above ground and joins to a manifold or valve.

RFT Tools use an exciter coil to generate a low-frequency AC field that permeates through the pipe. Detectors receive this energy and record the time of flight of the signal from the exciter which is linearly proportional to wall thickness, and the signal magnitude which is related to the surface area of a local wall loss.

For EMAT Tools, an acoustic (ultrasonic) wave is generated in the pipe wall by a coil which is positioned between the pipe and a strong magnet. The magnetic field is modified by the coil's oscillations which in turn varies the magnetic coupling to the pipe wall. The acoustic wave can be steered within the pipe wall by positioning the transducer at an angle, thereby allowing detection of axial or transverse cracks. EMAT Tools do not need an ultrasonic couplant and can be used in dry or wet pipes. They cannot measure through internal liners and tubercles may interfere with good coupling. They are also sensitive to proximity variations because the magnetic field coupling varies with distance. For best results the pipe should be clean and un-lined.

Conventional ultrasonic (UT) techniques employ transducers which emit an acoustic wave at high frequency which penetrates the pipe wall and measures internal and external wall loss. It requires a clean, bubble-free couplant in order to effectively couple to the pipe wall. UT Tools work well in liquid-filled pipelines. They cannot measure through liners and tubercles may interfere with proper operation; however, they are excellent for detection of axial and transverse cracks if the transducers are positioned suitably. UT Tools do not have to contact the inside of the pipe but will not work in gas-filled lines or partially full wet lines. UT Tools are ideal for clean, unlined water, waste water and oil pipelines.

Since UT and MFL techniques have been in use for over 50 years for testing of materials, their characteristics are well known and documented. EMAT and RFT, on the other hand, are relatively new techniques, having been commercialized only since the late 1980's.

While each of these techniques has advantages, there are also limitations .The following chart compares the strengths and limitations of each technique.

See formatting guidelines for tables.

Technique/Characteristic	**MFL**	**RFT**	**U.T.**	**EMAT**
Requires close contact with the material under test	Y	N	N	Y
Measures relative permeability and local stress	N	Y	N	N
Measures wall thickness of steel directly	N	Y	Y	Y
Measures Absolute and differential values	Y	Y	Abs	Abs
Relative speed	2m/sec	5m/min	0.1m/sec	0.1m/sec

Technique/Characteristic	MFL	RFT	U.T.	EMAT
Applicable for detecting pitting on outside of pipe	Y	Y	Y	Y
Equal sensitivity to O.D. and I.D. wall loss	N	Y	Y	Y
Requires clean, bubble-free liquid couplant	N	N	Y	N
Requires magnetic saturation of pipe	Y	N	N	N
Minimum flaw diameter detectable	0.25”	0.5”	0.2”	0.25”
Minimum depth flaw detectable	10%	20%	2%	5%
Accuracy (within plus minus)*	10%	15%	2%	5%
Requires pipeline change to add launcher	Y	Y	Y	Y
Experienced, verified technique	Y	Y	Y	Y
Can assess joint condition	N	N	N	N
Can detect leakage as well as wall loss	N	N	N	N

Table-1

*Depends on size of calibration defects being representative of defects in the pipe

Remote Field (RFT) has the ability to measure the remaining wall thickness in all three materials (steel, cast and ductile-iron) when in the presence of liners (cement mortar or P.E.); internal debris; internal scale or tubercles.

MFL, EMAT and U.T. require a relatively clean and smooth inner surface in order to couple their sensors to the pipe to measure the remaining wall thickness. RFT Tools; however, have all sensors contained within metal pressure housings that do not require contact with the pipe. Neither do they require magnetic saturation or liquid couplant.

Strengths of RFT for Pipeline Inspections

From Table-1 we can see that RFT has some notable advantages over MFL, UT and EMAT. The remainder of this paper focuses on the RFT technique.

Fig-9a) RFT Tool.

Fig-9b) MFL Tool.

One advantage that RFT tools have is their relative ruggedness. In Fig 9a) the RFT tool shown has no external moving parts (the red and blue straps are simply centralizers); therefore, there is very little that can damage the tool. In Figs 6 and 9b) the MFL tool's many fingers are seen. These are designed to hold the sensors against the inside of the pipeline. The fingers are necessary because MFL tools require close contact between the sensors and the pipe wall in order to achieve adequate sensitivity to defects. Fingers may be damaged when the tool passes through branches, valves and Tees.

Since 1990, RFT has been commercialized for a growing number of pipeline applications. It has been found that the advantages that RFT has over other electromagnetic techniques in boiler and heat exchanger inspections apply equally well to pipeline inspection tools.

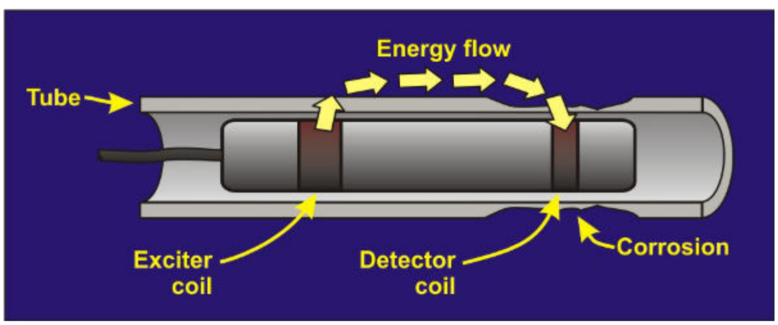

Fig-10: A simple RFT tool for small diameter tubing inspection

Fig-10 shows the basic principle of operation of a RFT probe. In the simplest configuration, there is one exciter coil and one detector coil. The exciter coil is energized with an AC sine wave at frequencies between 1Hz and 1KHz. The electromagnetic wave passes through the tube (pipe) wall near the exciter and re-enters the tube (pipe) at various distances from the exciter. At approximately 3 tube diameters, the field inside the tube has been reduced to near zero, while the external field has remained fairly strong. The net effect is that the detector coil receives its energy from the predominant external field, the circumferential eddy currents and the axial magnetic flux lines that are guided by the wall of the tube. It is because of this two-wall transmission path and its three sources of energy that RFT has earned its reputation of equal sensitivity to O.D. and I.D. defects.

One distinct advantage of RFT is its ability to measure wall thickness through scale, coatings and liners.

Internal tubercles are common in cast iron and steel water pipes. Scraping down to bare metal results in rusting that turns drinking water red for weeks; however, RFT is able to inspect cast-iron, ductile iron and steel pipelines through up to 25mm of scale, reducing the need for cleaning. This is not possible for MFL, UT or EMAT Tools

Fig-11: Showing internal liner in O&G Pipeline (left)
and tubercles in cast iron water pipe (right

In oil and/or waste water pipelines, sludge, sand, grease and wax often coat the walls. Removal of these deposits is costly. RFT Tools can inspect through these deposits, reading only the wall thickness of the pipeline.

Fig-12: internal grease, sand and oil deposits

RFT tools may be used in a tethered mode (useful for distances up to 3km) or in a free-swimming mode (distances up to 25km), in all sizes of pipelines with wall thickness up to 13mm.

RFT requires a relatively low inspection speed; however, this limitation is far outweighed by its ability to inspect through scale deposits and liners.

Conclusions

While each of the discussed techniques has strengths and limitations, it is the author's opinion that the RFT technique is the most versatile, especially for pipelines that contain internal scale, liners or tubercles. It also has the side benefit of detecting local stress in the pipeline.

For bare steel pipelines that are clean or have thin liners, MFL may be the best choice as it has the advantage of speed (especially important for long lines).

If resolution and sensitivity to small flaws is the most critical consideration, then the ultrasonic technique, or EMAT technique could present the most attractive alternative. Bear in mind that ultrasonic techniques require clean, bubble-free liquid in the pipe.

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