Increased Use of Remote Field Technology for In-Line Inspection of Pipelines Proves the Value of the Technology for this application

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Abstract

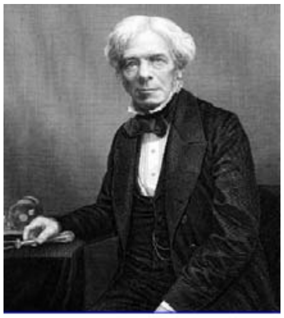
The in-line inspection of pipelines has been the domain of magnetic flux leakage (MFL) tools for half a century; however, there are many pipelinecs that cannot be inspected with MFL tools. Internal scale and deposits in water and sewer pipes; wax and low-flow conditions in oil pipelines; elbows and pipes with multiple diameters can be insurmountable challenges for MFL tools. For the past decade, Remote Field Technology (RFT) has been increasingly applied in these challenging conditions with good success. This paper discusses the basic principles of RFT and describes several case studies where RFT has been successfully used to inspect pipelines for corrosion, through thick liners and scale. MFL and RFT are compared for their respective strengths and limitations.

Keywords: RFT, MFL, in-line inspection tools, tethered, free-swimming, electromagnetic NDT.

1. Background

Since the early 1950’s pipeline operators have had to deal with the issue of corrosion (pitting) leading to costly, and sometimes deadly, leaks. Many solutions have been developed to mitigate corrosion (cathodic protection, liners, coatings, inhibitors and even non-metal pipelines); nevertheless corrosion leaks continue to be the number 2 cause of pipeline failures (behind third party damage).

While solutions to reducing the corrosion problem were being developed, the business of the detection of corrosion was also progressing. Through the well-established technique of *magnetic particle testing* (first used to detect cracks in cannon barrels in the 1800’s), it was observed that magnetic flux lines flowed in steel parts and were disrupted by discontinuities. It had also been observed that electrical currents were induced in wires when they were moved through a magnetic field, and that this effect could be enhanced by coiling the wire.


Michael Faraday

Michael Faraday discovered and documented the effect of electromagnetic induction. He published his paper in October 1821 in which he recorded the first conversion of electrical into mechanical energy and the notion of the “magnetic line of force”.

Faraday was not a mathematician, and almost all his biographers describe him as "mathematically illiterate". He never studied mathematics and his contributions to electricity were purely that of an experimentalist. However, it was Faraday's work which led to deep mathematical theories of electricity and magnetism.

Magnetic Flux Leakage, Eddy Current and Remote Field testing all have their origins with Michael Faraday's discovery of electromagnetic induction; however, it was not until the Second World War that these effects were put to practical use for testing materials.


Heinrich Lenz

Heinrich Lenz, born 1804, was a German physicist born in Tartu, which is today Estonia. In 1833 he formulated Lenz's law, a fundamental law of electromagnetism. He discovered that the strength of a magnetic field is proportional to the strength of the magnetic induction.

Lenz also reported investigations into the way electrical resistance changes with temperature, showing that an increase in temperature increases the resistance of a metal. Lenz studied the relationship between heat and current and discovered, independently of English physicist James Joule, the law (now known as Joule's law), which shows that heating effects accompany the flow of electricity in conductors.

James Clerk Maxwell, born 1831 in Edinburgh, Scotland is considered to be the “Grandfather of electromagnetic inspection techniques”. The greatest work of Maxwell's life was devoted to electricity. His most important contribution was the extension and mathematical formulation of earlier work on electricity and magnetism by Faraday and others into a linked set of differential equations.


James Clerk Maxwell

These equations, which are now collectively known as **Maxwell's equations**, were first presented to the Royal Society in 1864, and together describe the behavior of both electric and magnetic fields, as well as their interactions with matter.

Furthermore, Maxwell showed that the equations predict waves of oscillating electric and magnetic fields that travel through empty space at a speed that could be predicted from simple electrical experiments. Using equipment available at the time, Maxwell obtained a velocity of 310,740 km/s. Maxwell wrote in 1865: “This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself is an electromagnetic disturbance, in the form of waves, propagated through the electromagnetic field according to electromagnetic laws”. Maxwell proved correct, and his quantitative connection between light and electromagnetism is considered one of the great triumphs of 19th century physics.

The work of these pioneers led to the electromagnetic testing techniques that we use today.

2. Fundamentals

MFL, RFT and ECT (eddy current testing) all rely on voltages being generated in *coils* or *solid state devices* such as hall sensors. The voltages generated are dependant 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

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. If the material is relatively thin and the magnet relatively strong, then the material is said to be "saturated".

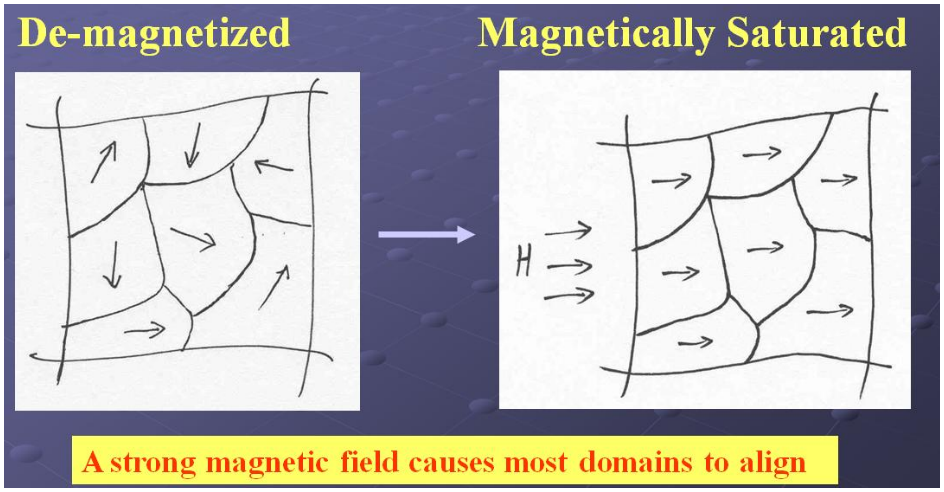


Fig-1: Depiction of magnetic domains within a ferrous metal

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 1.

Effective MFL inspection relies on magnetic saturation of the ferrous material in order to overcome magnetic permeability variations that are inherent in steels that have not been stress-relieved.

ECT and RFT techniques also rely on the rate of change of a magnetic field; however, the field is produced not by permanent magnets, but by an exciter coil, carrying alternating current. For ECT and RFT, saturation of the material is usually not attempted; hence magnetic permeability is measured along with wall thickness and proximity effects.

Since ECT and MFL techniques have been in use for over 50 years for testing of materials, their characteristics are well known and documented. RFT, on the other hand, is a relatively new technique, only having been commercialized since the late 1980's. The following chart compares the strengths and limitations of each technique.

Technique/Characteristic	**MFL**	**ECT**	**RFT**
Requires close contact with the material under test	Y	Y	N
Measures relative permeability and stress in the material	N	Y	Y
Measures wall thickness of steel directly	N (for coils)	N	Y
Measures Absolute and differential values	N (for coils)	Y	Y
Relative speed	2m/second	1.5m/sec	5m/min
Applicable for detecting pitting on far side of steel pipe/plate	Y	N*	Y
Equal sensitivity to O.D. and I.D. wall loss	N	N*	Y

*ECT requires magnetic saturation in order to penetrate steel plate or pipe

Table-1

3. Strengths of RFT for Pipeline Inspections

From Table-1 we can see that RFT has some significant strengths over MFL (ECT is not commonly used for in-line tools for pipeline inspection. It is sometimes used for surface crack detection, such as S.C.C.).

Fig-2a) RFT Tool.

Fig-2b) MFL Tool.

One advantage that RFT tools have is their relative ruggedness. In Fig 2a) 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 Fig-2b) the MFL tool has many "fingers" that are designed to hold the sensors against the inside of the pipeline. The fingers are necessary because MFL tools require intimate contact between the sensors and the pipe wall in order to achieve adequate sensitivity to defects. Fingers are often damaged when the tool passes through branches, valves and Tees, and there is a gap required between sensors to allow them to deflect inwards when passing over welds and dents.

Since 1990, RFT has been commercialized for a growing number of applications. Its most common application has been the inspection of heat exchanger and boiler tubes using internal probes connected to an external instrument. In more recent years, larger tools have been developed for applications such as pipelines and water well casings. 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.

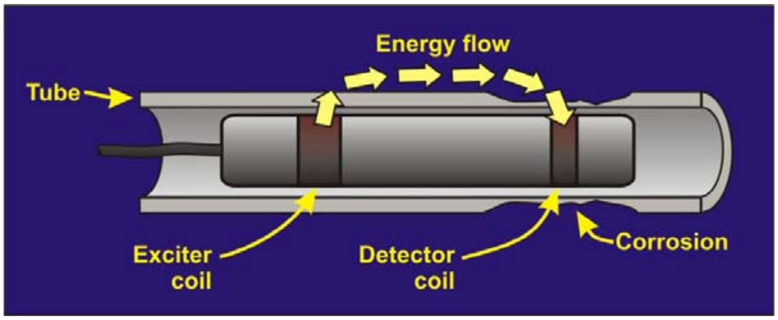


Fig-3: A simple RFT tool for small diameter tubing inspection

Fig-3 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 wall near the exciter and re-enters the tube 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 and the flux lines that are guided by the wall of the tube. It is because of this two-wall transmission path that RFT has gained 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, with approximately equal sensitivity to O.D. and I.D. wall loss.

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 25mm of scale, reducing the need for cleaning.

Fig-4a) and 4b) Showing internal scale in cast iron water pipe

In waste water pipelines sludge, sand and wax often coat the walls. Removal of these deposits is costly. RFT inspects through the deposits, reading only the wall thickness of the pipeline.

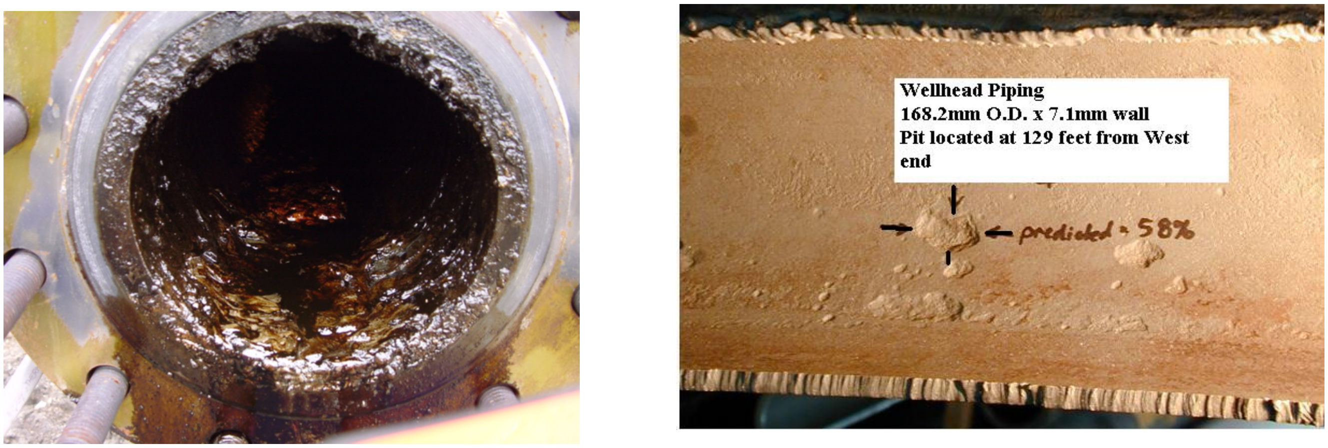


Fig-5a) and 5b) Wax, Sand and Oil deposits in O&G line

Wax, sand and oil deposits in oil and gas lines do not prevent RFT tools from measuring remaining wall thickness of the pipeline. The pits shown in Fig-5b) are from the same pipeline shown in Fig-5a). The pipeline was inspected without removal of the oil, sand and wax.

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.

Fig-6a) (above) showing a tethered RFT tool
Fig-6b) (right) showing a free-swimming RFT tool

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

A recent application of RFT was to inspect 45km of HDPE lined steel pipe in 150mm and 200mm sizes. The HDPE liner was in the order of 19mm thick. The tool was a free-swimming variety, and the inspection speed was held to 3.5m/minute in order to perfect the resolution. The tool was so sensitive (even at a sensor distance of over 25mm) that permeability variations (i.e. inherent stress) from the manufacture of the pipes were detected along with wall-loss defects.

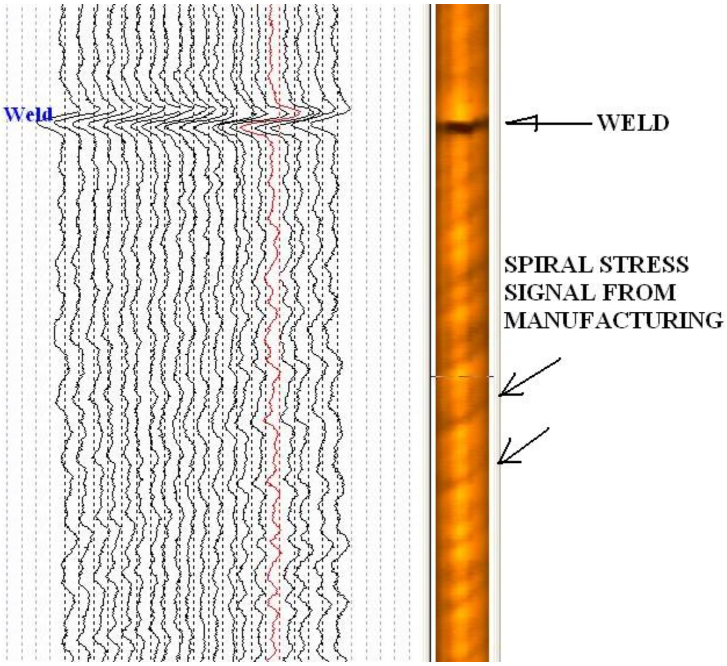


Fig-7a) 19mm HDPE liner in 200mm steel pipe

Fig-7b) Spiral stress pattern from manufacturing process.

Stress in operating pipelines can be caused by factors such as “bridging” (insufficient soil compaction under the pipeline); “surface loading” (stress caused by road or rail line crossing un-cased pipeline); sideways movement (in soft soils on hillsides, when pipeline tends to “walk” downhill); “rock pivot points” (pipeline resting on large rock which acts like a fulcrum) and “floating” (pipeline is in saturated soil and tends to float between any swamp weights).

The measurement of stress on pipelines is gaining interest from pipeline owners anxious to prevent leaks and failures caused by fatigue and stress corrosion cracking.

Of course, corrosion pits and FAC or erosion defects are detected along with the stress signal (which can be filtered out if desired).

Fig-8: Examples of pitting defects and flow-assisted corrosion detected by a tethered RFT tool.

Since the mid 1990's, RFT tools have been developed for many different Pipeline sizes and materials. Lines as small as 50mm and as large as 1981mm have been successfully inspected.

Pipeline materials varying from cast and ductile iron to drill steel, “Core-10, and carbon steel can be inspected for graphitization and corrosion pitting. The tools are high resolution, with data storage capability on-board.

Internal deposits and liners have been encountered: cement mortar, HDPE, epoxy, tar enamel and water scale. The maximum lift-off attempted to date has been 38mm for a deep water-well casing tool.

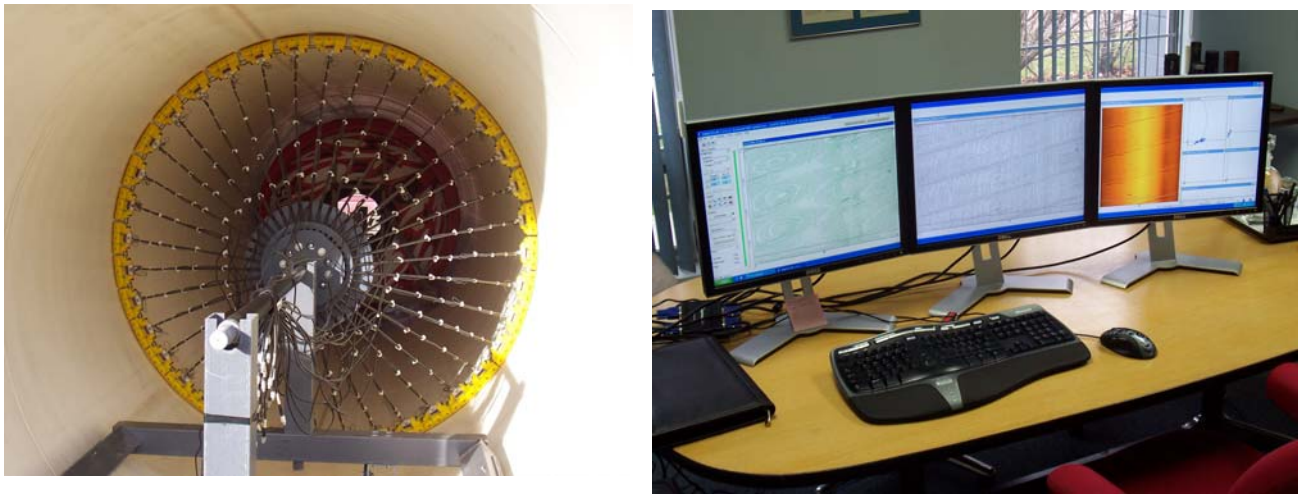


Fig-9: 1981mm, cement-lined steel pipeline with detector section of RFT tool and data from a section of the pipeline. Notice the spiral weld in the data and the stress patterns (swirls).

Conclusion

The inspection of pipelines using RFT is now well established, and interest is growing in the use of this versatile technique. RFT offers a viable alternative to traditional MFL inspection technique, with several significant advantages.

RFT in China has gained popularity in boiler and heat exchanger applications, and the technique is becoming more popular.

Chinese researchers at Russell NDE Systems have been instrumental in advancing RFT. Special thanks to co-author Shen Jianping; Dr. Yuwu Yu, Ellen Jin and Brian Thai for their tireless efforts in developing RFT for its various applications.