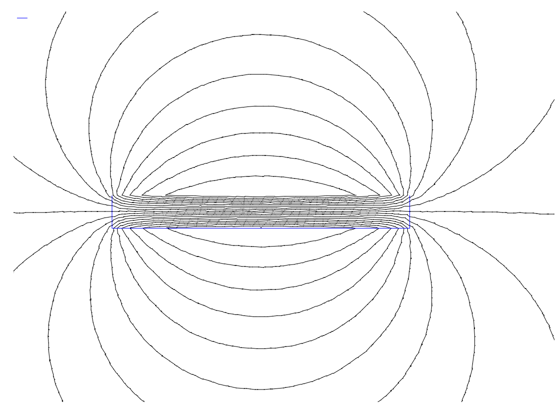
Detection of Wear in Oilwell Service Tubings using Magnetic Flux Leakage

Many methods have been developed and used for the inspection of oilwell service tubings to find wear, corrosion and fractures. One of the oldest, fastest, and thus most commonly used, is Magnetic Flux Leakage (MFL). This article will give a brief description of MFL and how it may be used to inspect oilwell service tubings.

Magnetism and MFL Basics

An understanding of MFL and how it can be used in inspection systems requires a basic understanding of magnetism, flux and permeability.

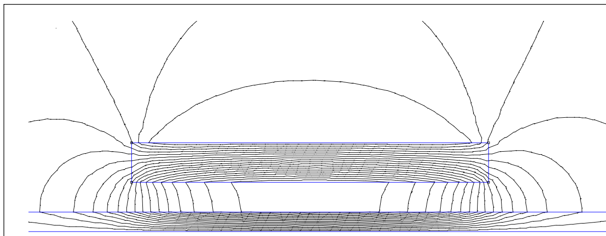
The first step in understanding MFL is examining the magnetic field generated by a magnet or electro-magnet. The diagram to the right shows the magnetic field produced by a common bar magnet (blue rectangle). Every magnet consists of two poles refered to as north and south respectively (the narrow ends of the magnet in the diagram on the right). The imaginary lines in the diagram are known as flux lines and are used to show both the strength and direction of the magnetic field. The closer the spacing of the flux lines correlates to a relatively stronger magnetic field and is refered to as the flux density. A common simple experiment to visualize a magnetic field is the use of iron filings (a magnetic material), sprinkled over a sheet paper (non-magentic material) covering a magnet.



Magnetic "flux" field around a Magnet

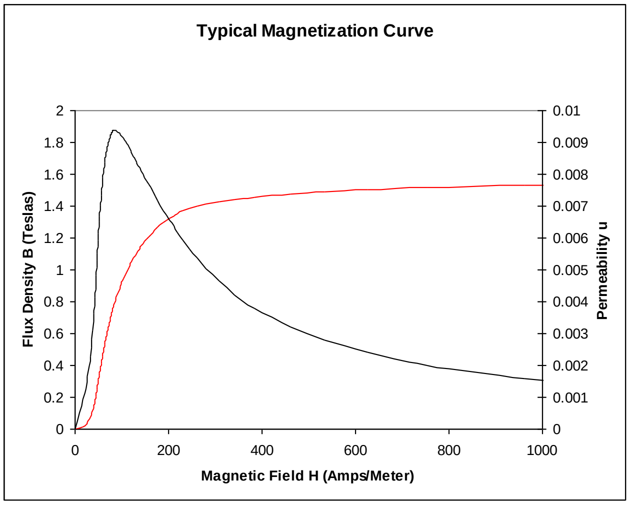
Magnetic flux prefers to travel through some materials (ferromagnetic: iron, nickel, cobalt, etc.) more than others (air, vacuum, aluminum, copper, etc.) This can be seen in the following diagram of the same bar magnet placed close to iron metal sheet.

The majority of the near side flux lines flow through the iron sheet, as well as a number of the flux lines from the far side of the magnet.



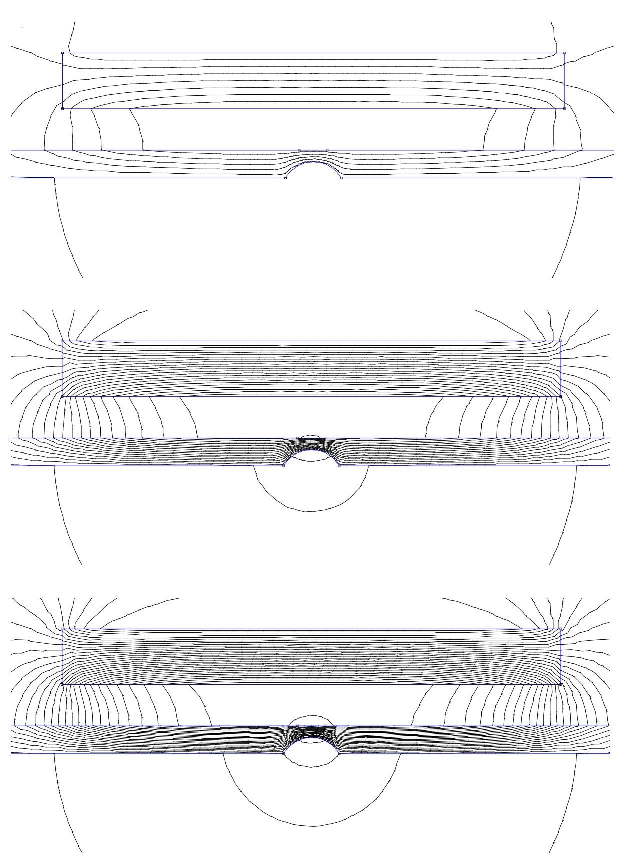
Magnetic "flux" Field of a Magnet near an Iron Sheet

The preference of the magnetic field to pass through the ferromagnetic iron sheet is not a constant and tends to decrease for higher values of flux density. A magnetization or B-H curve is commonly used to show this relationship as shown by the red line in the graph to the right. The ratio of flux density to field strength at any given point is referred to as the permeability, µ, of the material and is the measure of the ability of magnetic flux to permeate a magnetic material. The horizontal axis 'H' represents the applied magnetic field and the vertical axis B represents the induced flux density in the respective material. The preference for magnetic flux to travel through a ferromagnetic material is not constant but changes with the strength of the magnetic field.



Non-magnetic materials, for the purposes of this discussion, are not affected by constant magnetic fields and behave very near the same permeability as a vacuum. The magnetization or B-H curve for a vacuum has a slope of $4\pi \times 10^{-7}$ which corresponds to the fundamental physical constant μ_0. The B-H curve of ferromagnetic materials will asymptotically meet μ_0 the higher the applied field strength. Generally the permeability of a material is given relative to μ_0 or $\mu_r = \mu/\mu_0$. If the permeability of a material is greater than 1.0 it is generally the relative permeability.

The term saturation point is commonly defined as that point beyond which incremental increases in the applied magnetic field yield less incremental increases in the induced flux density. Typically this point is near the middle of the knee in the B-H curve or the maximum permeability. The change in permeability of the iron material is what causes a local thinning of the material to exhibit the phenomenon of flux leakage. The diagram to the right illustrates less flux leakage when the flux density is low and



MFL vs Flux Density

progressively more as we get closer to saturation and then beyond.

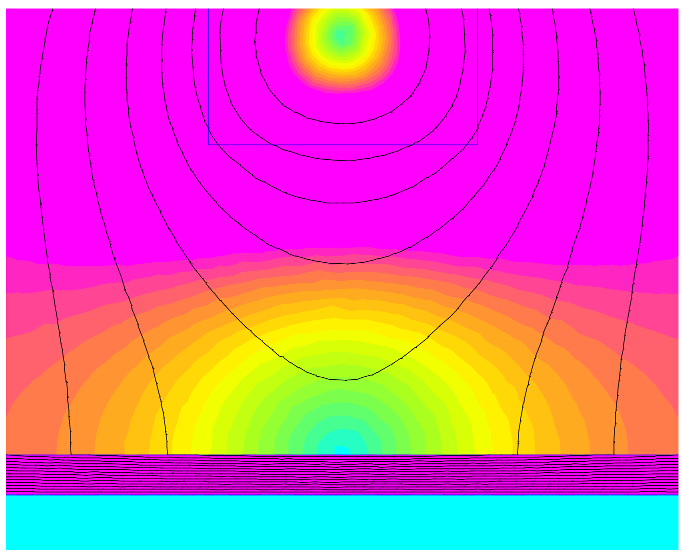
Oilwell Tubing Inspection

The easiest method to apply a magnetic field to an oil well service tubing is by way of a circumferential electromagnetic coil. Both longitudinal and perpendicular magnetic flux components can be induced in the tubing by setting an axis offset between the electromagnetic coil and the tubing. By using two or more coils with appropriately placed sensors on the surface of the pipe, 100% coverage of the tubing in both length and circumference can be performed with fixed coils.

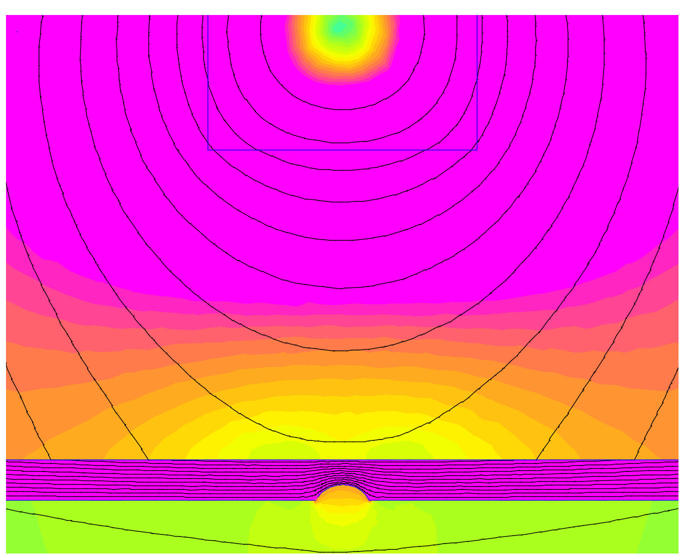
Localized and Circumferential Wear Patterns

The three diagrams below show the area between the coil and a longitudinal view of the wall of the tubing. The flux density has been color coded and expanded in the range of interest with magenta coded for the higher flux density and above to blue for a lower flux density and below.

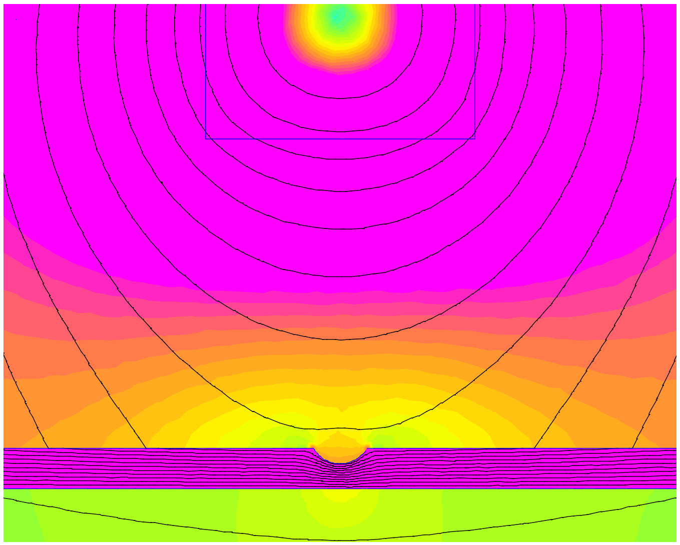
The first diagram shows the normal flux lines and color encoded flux density with no defects.



The second diagram shows the same area when a small divot of tubing material is removed from the inside surface of the tubing. Notice the increase in flux density just above the tubing along the vertical axis of the coil.



The third diagram shows the tubing wall loss on the outside of the tubing.

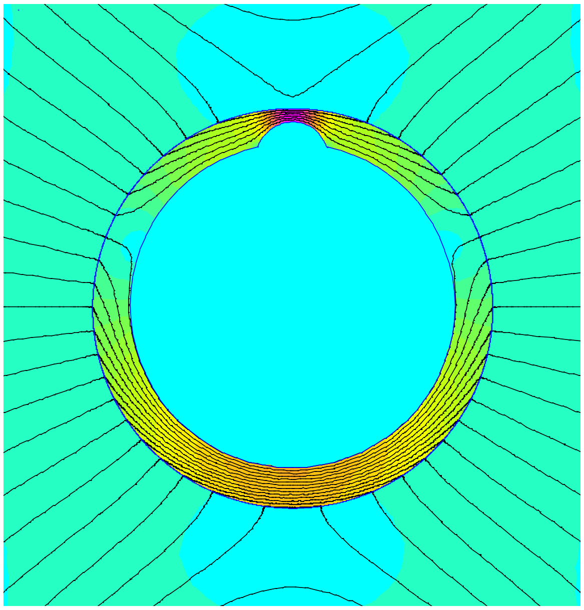


An array of magnetic sensors, such as Hall Effect sensors, placed along the circumference of the pipe can be used to map the defects as they move down the length of the pipe.

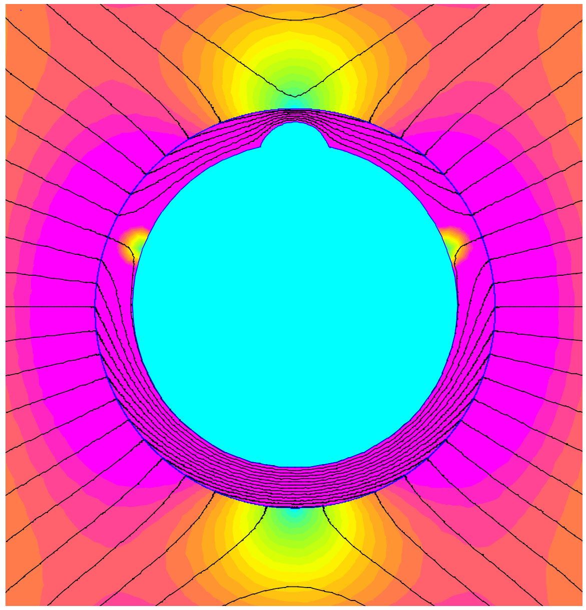
Longitudinal Wear Patterns

Longitudinal wear patterns are harder, but not impossible, to detect using this apparatus. Due to the geometry of the tubing in this axis and the magnetic field the MFL effects are reduced but still detectable.

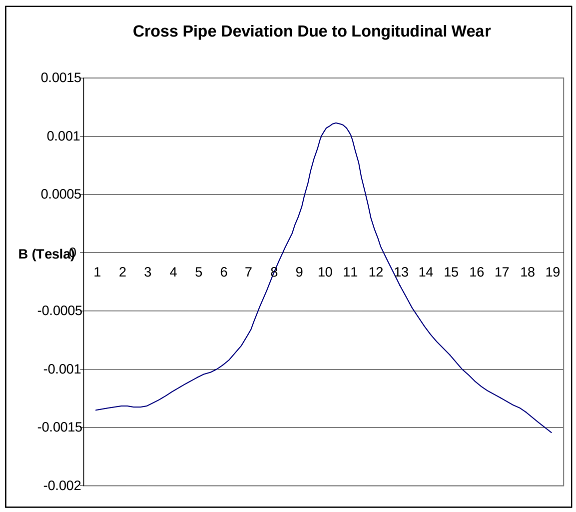
The diagram to the right shows the effect of a semi-circular longitudinal wear. It can be seen that some of the magnetic flux has been shifted to the unaffected side of the tubing and that the wear point has caused a concentrating effect on the flux density.



Even after zooming in the flux density color coding it is still hard to see the effect of MFL at the wear location.



Comparing the flux density near the surface of the tubing near the wear and opposite the wear we see the effect with an amplitude of around 2.5 mT or about 25 guass in this simulation. This is well within the capabilities of a standard linear Hall Effect sensor.



Conclusion:

Magnetic Flux Leakage can be used to detect the various types of wear in ferrous oilfield service tubing using properly aligned, near saturation, magnetic inducing fields. Magnetic sensor such as linear Hall Effect types placed close to the tubing and in properly aligned arrays can be used to map the flux leakage. Properly calibrated sensor arrays and appropriate software algorithms can be used to gather and process the data to identify and quantify the type and degree of wear present. Both axial and circumferential wear, inside and outside the tubing, can be detected, covering the numerous types of wear. Real-time analysis of tubing condition can be accomplished during the extraction phase of oilwell servicing at standard tubing extraction rates with a modest amount of computing power.