Magnetic Eddy Current (MEC) Inspection Technique

Introduction

Eddy Current Testing (ECT) is a well established technology for the inspection of metallic components for surface breaking flaws. It is used for component testing in the aviation and automotive industry. It can also be used to find flaws in the volume of structures of non-ferritic metal. A variation of eddy current testing is the magnetic eddy current testing, which allows finding flaws in the volume also of thick ferritic steel components.

Standard Eddy Current Testing

The basic principle of eddy current testing consists of measuring the impedance of an electrical coil. The impedance is its complex resistance, which also depends on a property called inductance. The inductance is a physical property of a coil that describes how a magnetic field is generated, when an electrical current is sent through it.

Electromagnetic theory shows that the effect of inductance leads to a phase shift and amplitude change in the current, when an AC voltage is applied to the coil. The inductance of a coil can thus be measured by measuring the AC resistance (impedance) of the coil. It depends on the size of the coil, the number of turns and most importantly on the electromagnetic properties of all materials in the vicinity of the coil.

A coil in the vicinity of a metallic surface will have a different impedance as compared to the same coil in air. Moreover, a coil close to a metallic surface will have a different impedance depending on whether the metallic surface is flawless or it has a crack. This is the basis of eddy current testing. To understand the abilities and limitations of eddy current testing better, a few more details are required.

The details of the set-up are shown in Figure 1 and Figure 2. An AC current flows through a coil. An AC magnetic field is generated around the coil. If the coil is in air, the magnetic field only depends on the nature of the coil (its inductance). If the coil is brought closer to a metallic surface, the magnetic field will penetrate into the metal piece.

According to the law of electromagnetic induction, an AC magnetic field will lead to the generation of currents in the surface. These currents generate a magnetic field that, according to Lenz's Law, is opposed to the initial field. It weakens the original field and thus influences the inductance of the coil. Anything that changes the nature of the eddy currents in the metal can thus be detected by a change in the impedance. Naturally the vicinity of the coil to the surface and the presence of a crack in the metal are such influences on the eddy currents. The deeper the crack, the more it will impede the flow of currents in the surface and the higher the effect.

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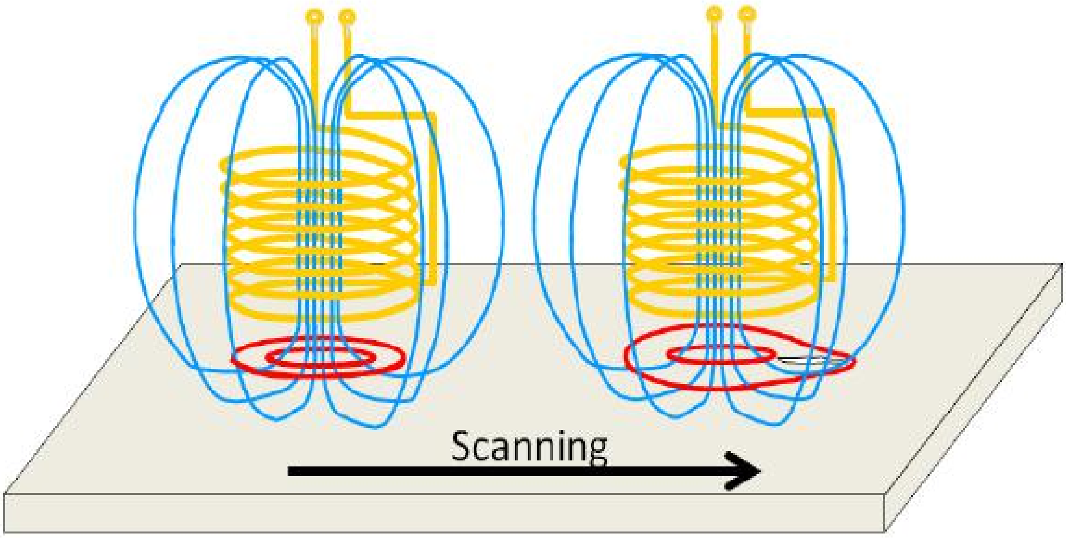

Figure 1: The concept of eddy current testing

It lies in the nature of electromagnetic induction that the currents flow in the surface only (skin-effect). The degree to which they will penetrate into the bulk of the material depends on the material properties. Electromagnetic theory shows that, the higher the frequency of the currents and the higher the conductivity and permeability of the metal, the more the currents will be confined to the surface. Standard eddy current techniques employ a frequency of a few kHz to MHz. This means that stainless steel tubes of a few mm wall thickness can be inspected, while on carbon steel tubes only surface effects are detected. The effect of limited penetration depth is shown on the right of Figure 2.

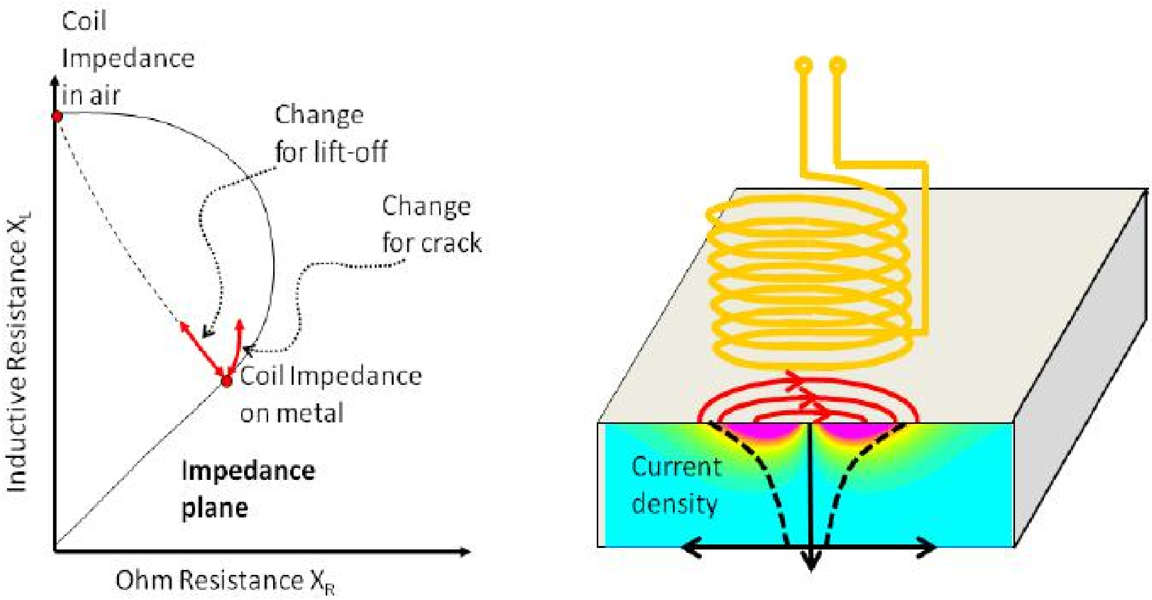

Figure 2: Left – The impedance plane shows the signal in two dimensions.
Right – The limited penetration depth determines the sensitivity with regards to frequency

The coils used for inspection vary considerably in size, shape and design. Single coils are used (absolute coil) or two coils can be used in a bridge mode (differential coil). The latter makes the arrangement very sensitive to sudden changes, while the first is more suitable for the detection of gradual changes in material properties. Also coils can be arranged in a send-receive set-up. In general, it can be said that the smaller the defect to be detected, the smaller the coil should be and the closer it should be to the surface.

The instrumentation itself then consists of a scanner that holds sensors in a predefined distance to the surface (lift-off) and allows moving them smoothly in a certain direction. The electronics carry out a phase-sensitive detection to determine the complex impedance. The value of the impedance is shown in the impedance plane (the left of Figure 2). As the sensor moves over a surface, the locus point of the impedance changes.

Magnetic Eddy Current

As pointed out above the limited penetration depth of eddy currents in ferritic steel does not allow for testing of steel, unless the interest is only in surface breaking flaws. If a ferromagnetic material is magnetised, this will reduce the permeability of the material. The eddy currents penetrate deeper into the material and potentially other types of defects are picked up. In a typical testing set-up on ferritic material, the penetration depth can be increased from 1 mm to 4 mm by magnetising the sample1. This is still not enough if far-side defects in a pipe with 1 inch wall thickness should be detected. A different method of interaction needs to be used.

Another effect is helping in case of high wall thickness ferritic pipe. Wherever the pipe wall cross section is reduced due to corrosion or other material flaws, the magnetic flux lines will concentrate. This leads to a higher magnetisation and a lower permeability. The change in permeability changes the impedance of the coil and will thus create a signal. The principle is illustrated in Figure 3.

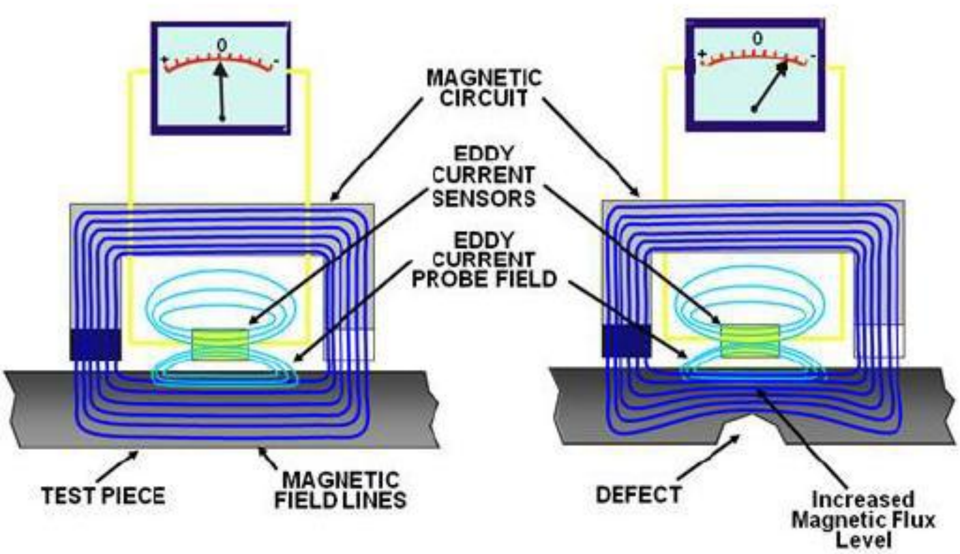

Figure 3: The MEC measurement principle

[1] The eddy currents decay exponentially with increasing depth. The penetration depth refers to a decay down to 1/e (37%) of the surface level

Innospection uses this technique with its MEC devices. Since only moderate levels of magnetisation are required, the method works to higher wall thickness pipe, or through several millimetres of coating thickness.

For an illustration Figure 4 shows the typical variation of the relative permeability with the applied field (and hence the magnetisation). The left shows a typical magnetisation curve. The hysteresis is typically small for steel but measurable. As a unique reference, often the anhysteretic curve is used. One possible definition of permeability is the slope of this curve as shown in the right of Figure 4.

As can be seen the permeability approaches 1 for high fields which lead to a saturation of the material. Changes in permeability due to flux concentrations are small and the best detectability of defects is expected at lower fields. Some devices use an electromagnet as a magnetising unit. The current is varied to measure the signal amplitude of the defect and optimized accordingly. Other devices use a permanent magnet with a shunting mechanism to allow for adjustment of the magnetisation level. Obviously the optimum signal is found at a value below the maximum possible magnetisation level.

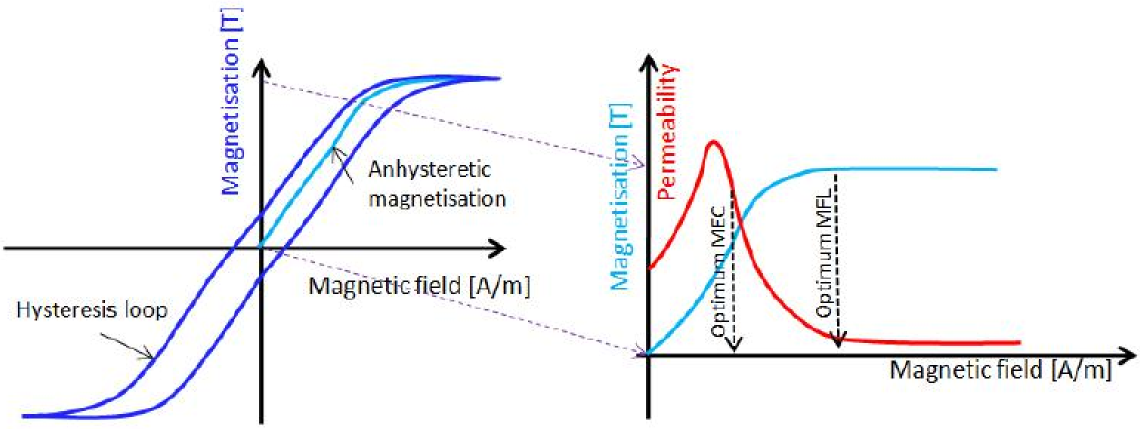

Figure 4: Change of permeability with magnetisation level

It is important to understand the difference to MFL. By the set-up the two methods look quite similar. However, MFL requires a leakage field to be measured. The magnetic biased method senses on the surfaces of the pipe wall. For a repeatable signal in MFL a magnetizing field of about 10 kA/m is usually required as a minimum. In magnetic biased eddy current a field of 3 kA/m is usually sufficient. The requirement for a minimum magnetisation level is due to the need to discriminate other permeability related signals. Pipeline stresses or material inhomogeneities may be in interesting aspect for inspection. However, a clear distinction to defects is required.

The above said is valid for the detection and measurement of far-side defects. For near-side defects the standard eddy current lift-off measurement is used for the detection of cracks or corrosion. A coil changes impedance if it is closer or farther away from a conductive surface. Both effects, the change in permeability and the lift-off, occur at the same time. The effects can be distinguished by the phase of the impedance change in the impedance plane. The origin of the different phase orientations is shown in Figure 5. Obviously the exact phase difference depends on the frequency. For MEC it can be set such, that it is approx at right angles.

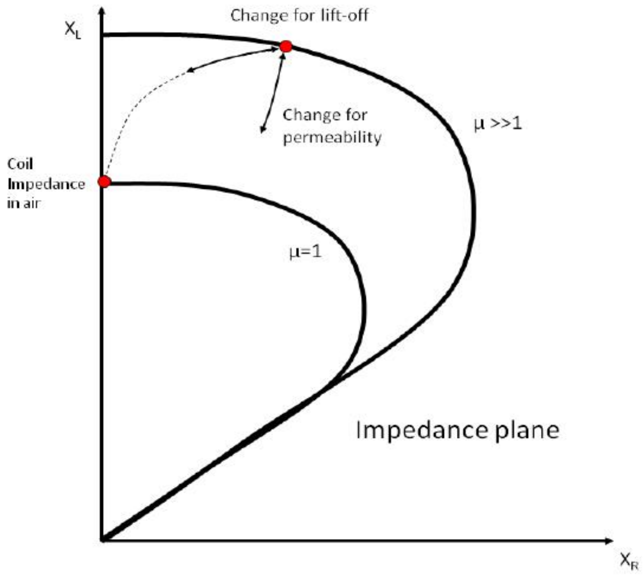

Figure 5: Impedance plane for distinction of far-side and near-side defects

The phase of the change in impedance will reveal the nature of the defect. For both types, far-side and near-side a calibration can be set-up. In the used wall thickness range and lift-off arrangement the curve of signal amplitude versus depth is nearly linear. The calibration curve is established with artificial defects on calibration plates. A calibration plate usually comprises of defects of 20%, 40%, 60% and 80% wall loss. The procedure is illustrated in Figure 6.

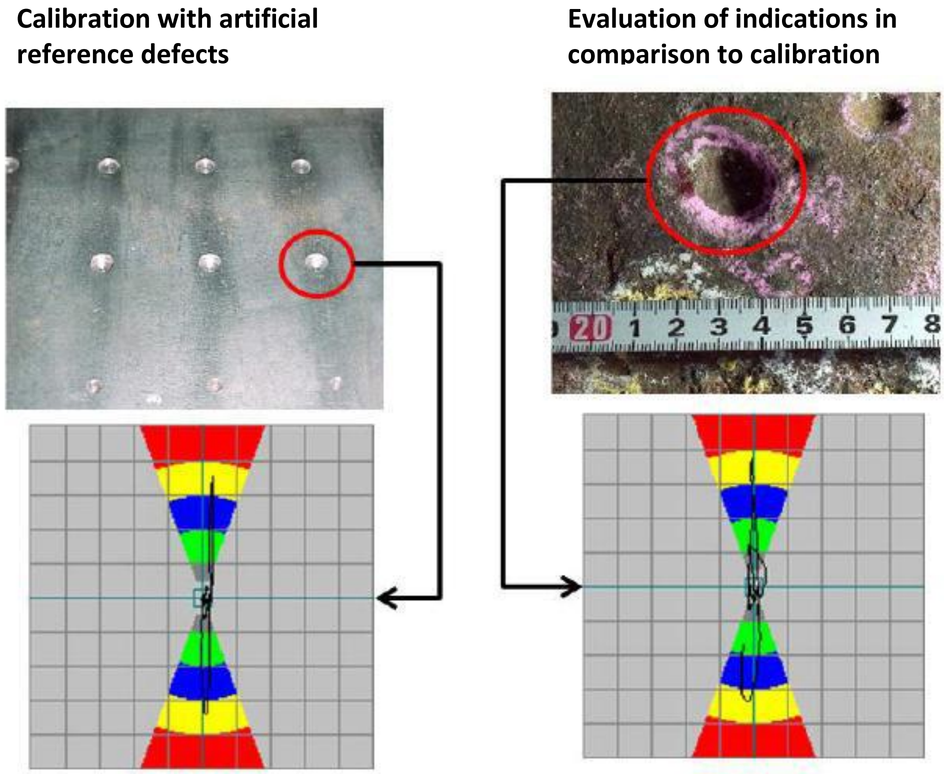

Figure 6: Left side – Signal obtained from a machined defect on a plate
Right – Signal of corrosion defect of comparable size

Advantages of MEC Technique

Typical Sensors

One of the advantages of the MEC-technology is the ability to tailor it to different applications. This is the case because of the large variety of sensing devices that can be used. Eddy current sensors can be produced in many ways all of which have their specific area of application. The main parameter for the adjustment to a specific scope is the size, the strength the frequency and the orientation of the magnetic AC sensing field. For the sake of defect discrimination several sensing parameter can be combined into one sensor. This will generate several sets of data at one inspection scan and will allow for the classification of signals into different defect types.

In comparing the method to other methods, the advantages can be described as follows:

Comparison to MFL

- A lower magnetisation is required or respectively with a given magnetisation unit a higher wall thickness can be inspected. In particular for internal pipe inspection the volume to generate a magnetic flux level in the pipe is limited. For some low diameter high wall thickness pipe, the achievable magnetic flux level is not sufficient. This limit is pushed much further with the MEC-technology.

- The eddy current sensor is an active sensor generating its own field. The sensing takes place in the metal itself, not outside of the metal. This sensing field can measure over higher distances.

Comparison to UT

- As an electromagnetic method the requirements for cleaning are not paramount. As long as the scanner is able to pass a measurement through non-metallic debris is possible.

- As a pure electromagnetic technology it can sense through a non-metallic coating of several mm. In specific set-up a sensing through 15 mm of coating has been done.

- MEC can also sense through a metallic non-ferritic coating. The sensing parameter need to be adjusted accordingly. Sensing through 3 mm of stainless steel or Monel has been carried out in many instances. It does not matter whether there is a bonding of this metallic component to the ferritic steel component.

- The magnetisation leads to a signal volume, which extends much wider than the defect itself. This allows finding even small defects. The detection of pin-holes is possible.

Comparison to low frequency electromagnetic methods (Remote Field, etc)

- Since the involved frequencies are comparatively high, the speed of the scanning is not limited due to the signal propagation. Scanning limitations are only given by the typical DC-Magnetic field time lag.

Conclusion

The MEC-Inspection technique is a unique sensing technology the advantages of which are not yet fully exploited in the Oil and Gas industry. The application as a possible ILI-technology seems especially interesting.