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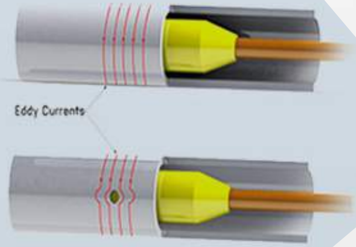
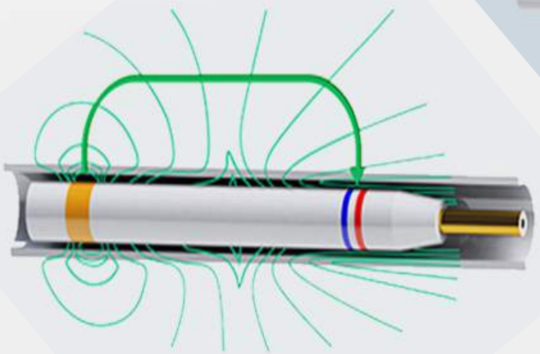
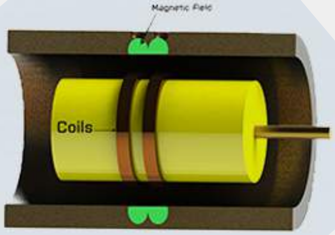
Electromagnetic Simulation for NDT/NDE Applications using EMS inside SOLIDOWRKS and Autodesk Inventor







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Non-Destructive Testing Techniques:

Non-destructive testing (NDT) is nowadays widely used for many applications in the aerospace, petroleum and civil engineering and many more manufacturing and service environments to ensure safety and production quality.

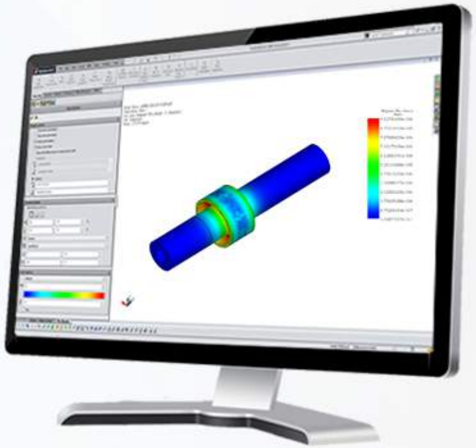
NDT is divided into various methods of nondestructive testing, each based on a particular scientific principle such as the Electromagnetic testing. Electromagnetic inspection is the non-destructive testing method which includes magnetic fields and electric currents. It allows to measure a response caused by a defect on a non-ferrous metallic or ferromagnetic object.

Electromagnetic testing techniques involve the following methods:

- Eddy Current Testing
- Alternating Current Field Measurement
- Magnetic Particle Inspection
- Magnetic Flux Leakage
- Pulsed Eddy Current
- Eddy Current Thermography

EM simulation using EMS inside SOLIDWORKS for Non-destructive Testing techniques

EMS, developed by EMWorks, Inc, is an electromagnetic simulation suite based on Finite Element Method. It solves static, frequency domain and transient electromagnetic problems using respectively static, time-Harmonic, and Time stepping FEM solvers. EMS addresses static magnetic and electric fields, electromagnetic induction, eddy currents, skin effect, proximity effect, electromagentic forces and torques.



• EMS is fully integrated inside SOLIDWORKS and Autodesk Inventor inherting their high capability and flexibility in CAD modeling.

• With thermal, structural and motion coupling, EMS is considered as a full multi-physics package.

• EMS helps to analyze, interpret and optimize inputs and outputs of NDT applications. Using EMS Magnetic modules (Magnetostatic, AC Magnetic and Transient), thermal and motion coupling , wide range of NDT sensors can be studied.

Eddy Currrent Testing

Eddy Current Testing (ECT): is an NDT technique that helps to efficiently examine large surfaces of electrically conductive material using electromagnetic laws. It does not require any use of coupling liquids or any contact with the specimen. It is used mainly for non-ferromagnetic materials because of their small skin depth.

In addition to surface and subsurface flaw inspection, ECT can be used to determine a variety of material properties, identify corrosion, etc.

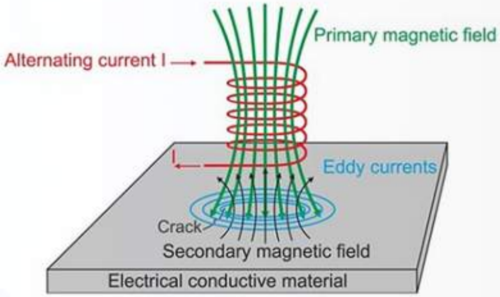


Figure 1: Eddy Current Testing principle [1]

Example 1: TEAM Problem 15 [2]

This problem consists of a coil moving on top of an electrical conductive plate (Figure 2). A high frequency current is injected into the stranded coil. The magnetic flux generated by the coil creates eddy currents in the plate which affect the impedance of the coil.

The AC resistance and inductance results of the coil for both cases of the plate -with and without crack- are computed with EMS and compared to ref[2]. Thanks to the symmetry, only half of the model is simulated to save the computation time. A parametric AC Magnetic analysis inside EMS is used to solve this problem.

The parameterization analysis of EMS allows to vary both geometrical and simulation variables and run multiple scenarios for the same model.

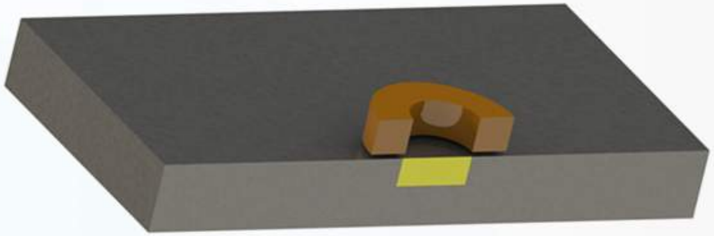


Figure 2: Simulated model

Figure 3a) and 3b) show the distribution of the magnetic flux density respectively, for the plate -without and with- crack (the coil at the position 0 mm). As can be seen, both results represent a small gap because the tested plate is made of non-ferrous material (relative permeability equal to 1). The air and the plate behave in the same way regarding the magnetic flux. The resultant gap in the results is due to the magnetic flux generated by the induced eddy currents. The magnetic field reaches a max of 1.93T in absence of the crack while it is 1.91T in the second case.

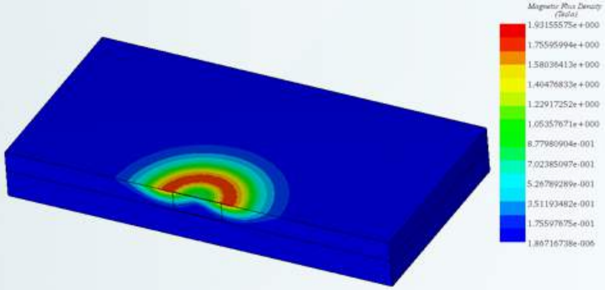


Figure 3a: Magnetic flux density distribution in case of plate without crack

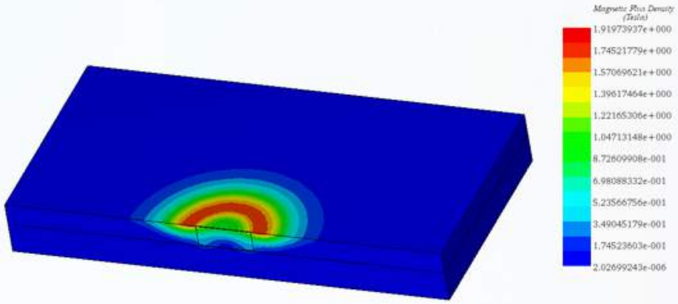


Figure 3b: Magnetic flux density distribution in case of plate with crack

Example 1: TEAM Problem 15

Figure 4a) and 4b) demonstrate the eddy currents distribution in the plate respectively without and with crack. Figure 4b) shows a discontinuity in the plot because there is no eddy currents in the crack region (Air).

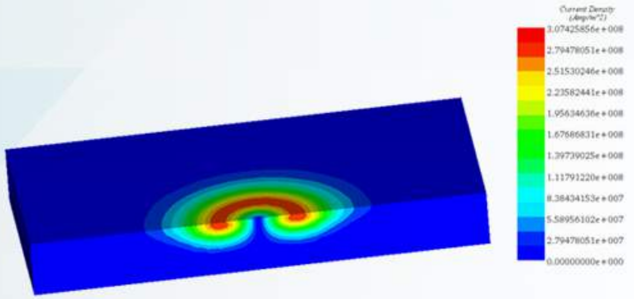


Figure 4a : Eddy current distribution in case of plate without crack

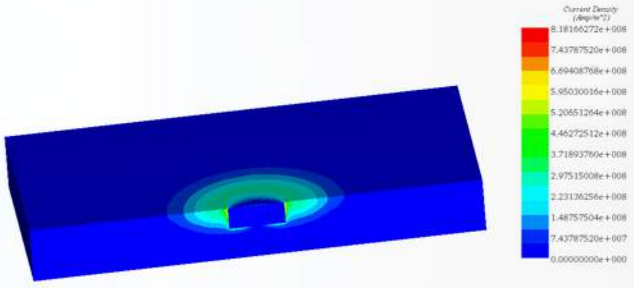


Figure 4b : Eddy current distribution in case of plate with crack

The Figure 5 contains a 3D vector plot of the eddy curent distribution. It represents peak values in the end crack zones. This can be explained by the end effect phenomenon.

Figures 6a) and 6b) contain the results of the variation of ΔL and ΔR versus the coil position computed by EMS and published by ref [2]. These obtained results can help to identify the crack.

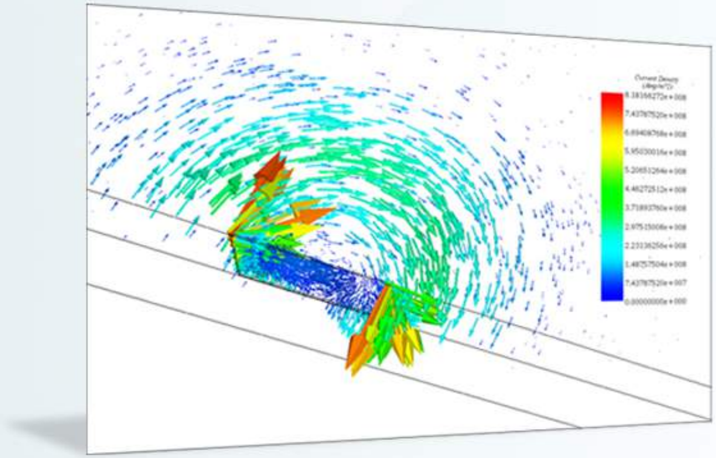


Figure 5: Vector plot of the eddy current near the crack zone

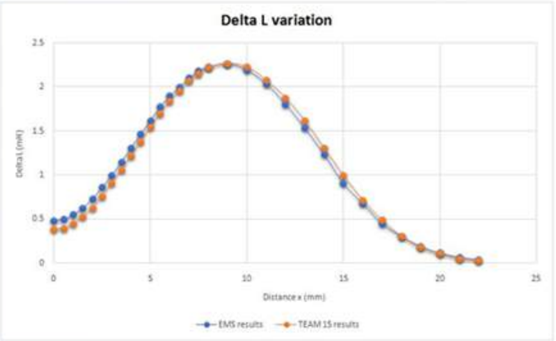


Figure 6a: Variation of the coil inductance

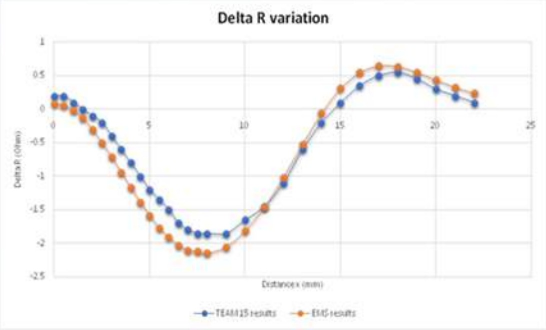


Figure 6b: Variation of the AC resistance

Alternating Current Field Measurement (ACFM):

Alternating Current Field Measurement (ACFM) is an electromagnetic technique that permits non-destructive detection and size estimation of cracks extending to the surface of ferrous and non-ferrous metals. It is important because it is a technique that is applicable to test both ferrous and non-ferrous materials. The ACFM sensor, which is composed of one or more coils, creates eddy currents on the tested specimen. These eddy currents are disturbed in the presence of an exposed crack which also causes a disturbance in the magnetic field above the surface.
This variation in the magnetic field is measured and analyzed to both locate and size the crack.

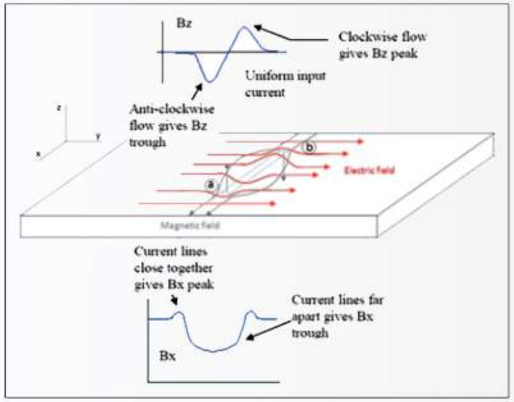


Figure 7: Alternating current field measurement principle [3]

Example 2: ACFM Twin Coils Probe

The ACFM probe (Figure 8) contains two coils and a magnetic sensor packaged inside a container. The container is made of plastic
(a non-magnetic material). The magnetic sensor can detect the value of the magnetic flux density when the probe is kept in contact/close to the test surface. The probe is typically scanned along the direction shown (Figure 9). The magnetic flux density in the X direction (Bx) is measured by the sensor. When there is no crack, the value of (Bx) is more or less uniform but when a surface crack is detected, the value of (Bx) gets to a peak. This variation of the magnetic flux is caused by the effect of the crack on the induced eddy current in the conductive plate.

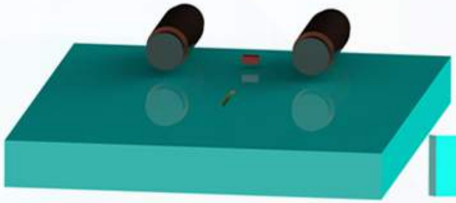


Figure 8: 3D CAD model of the ACFM probe

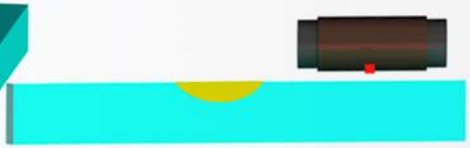


Figure 9: Cross section view of the simulated model

AC Magnetic module coupled to motion analysis is used to solve this NDT application.

Figure 10 and Figure 11 show respectively 3D vector plot of the magnetic flux density and the eddy currents density in the steel specimen. Peak values of the magnetic flux and the eddy currents are detected at the crack extremities (End effects).

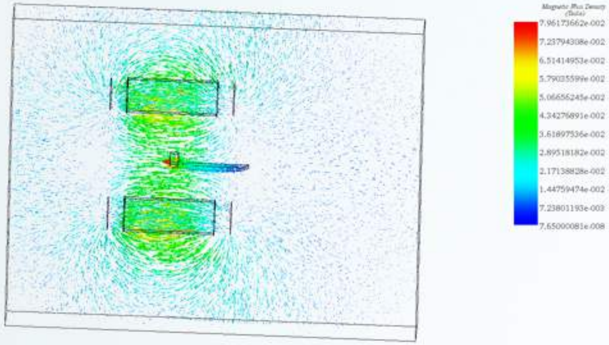


Figure 10: Magnetic Flux Density Distribution (with crack)

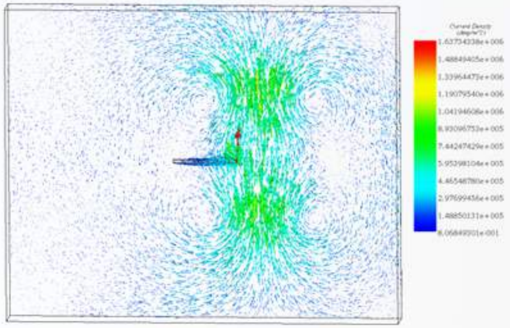


Figure 11: Eddy Currents Distribution (with crack)

Alternating Current Field Measurement (ACFM):

Figure 12 and 13 show respectively the components (Bx) and (Bz) of the magnetic field detected by the sensor. The captured signal of (Bx) represents a symmetric curve. By analyzing only a half of the curve, the measured (Bx) starts by increasing until reaching its maximum value (5.4G) at 20 mm then it drops down until it arrives to its minimum value (4.5G) at 30 mm. The peak values of the magnetic field and the eddy currents shown in the previous figures can explain the maximum values of the magnetic flux sensed by the probe. The crack extremities and length can be estimated by these peak values (20 mm and 40 mm). From Figure 12, the center of the crack is at the position 30 mm. The crack depth is predicted by intrepreting (Bz).

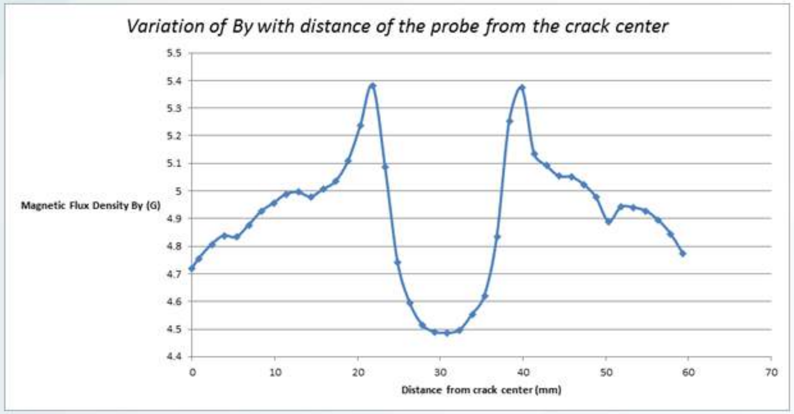


Figure 12: (Bx) component of the magnetic field captured by the sensor

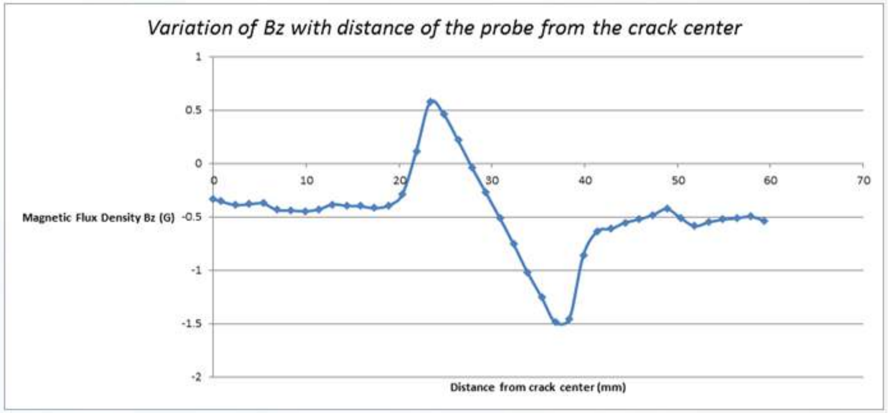


Figure 13: (Bz) component of the magnetic field captured by the sensor

The figure below represents a cross section view of the magnetic flux generated in the tested plate. This vector plot could help to estimate the maximum allowed distance separating the sensor and the tested object to ensure an accurate detection of the signal.

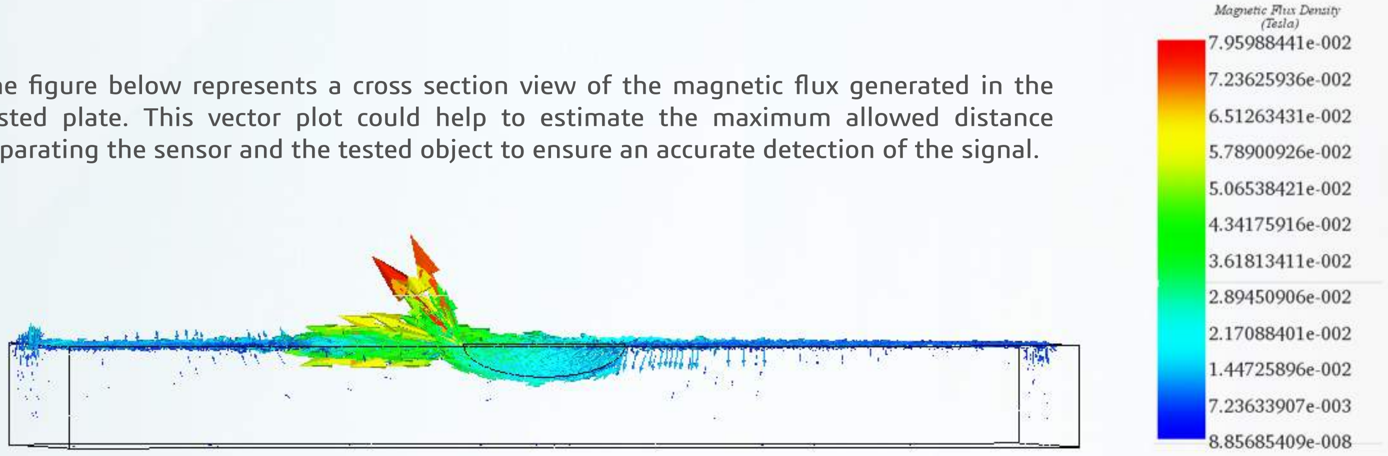


Figure 14: Section view of a 3D vector plot of the magnetic flux density in the plate

Magnetic Flux Leakage (MFL) :

MFL is a magnetic method of non-destructive testing that is used to detect corrosion, pitting and wall loss in steel structures. It uses permanent magnets or electromagnets to magnetize the tank floor then the resulting magnetic field changes are recorded and analyzed. If there is corrosion, pitting or wall loss, the magnetic field 'leaks' and the 'leakage' is analyzed to determine the location and severity of the defect of the tank floor, in case of both near and far surface.

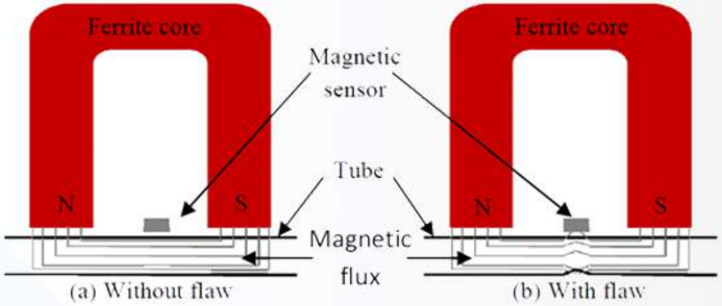


Figure 15 : Magnetic Flux Leakage principle [4]

Example 4: MFL pipe scanner

This example consists of a sensor based on magnetic flux leakage principle. Two permanent magnets, attached on a ferromagnetic carriage, are moving in the proximity of a steel pipe. The pipe contains three defects with different sizes. A cross section view of the simulated example is shown in Figure 16.

A Magnetostatic module of EMS coupled to motion analysis is used to study this case. The sensor under the carriage is used to detect the magnetic flux leaked through the pipe surface.

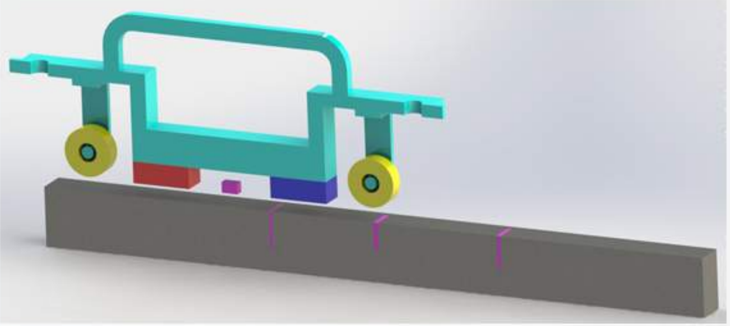


Figure 16: Cross section view of the 3D model

Figure 17 and Figure 18 show, respectively fringe and vector plot of the magnetic flux density computed by EMS for the whole model in two different positions. Figure 19 illustrates the output signal of the sensor in case of pipe -with and without- defects. The red curve constitutes the captured flux leaked through the pipe caused by the presence of defects. It has different maximum values due to the different crack sizes. This output result helps to determine the position and the depth of each crack.

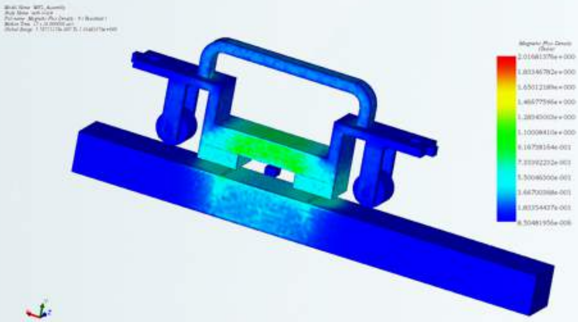


Figure 17: Fringe plot of the magnetic flux density

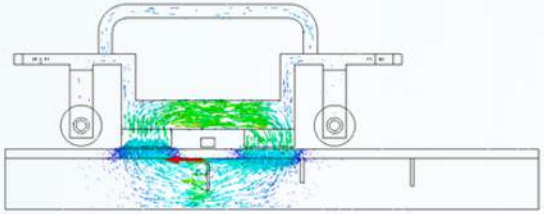


Figure 18: Vector plot of the magnetic flux density

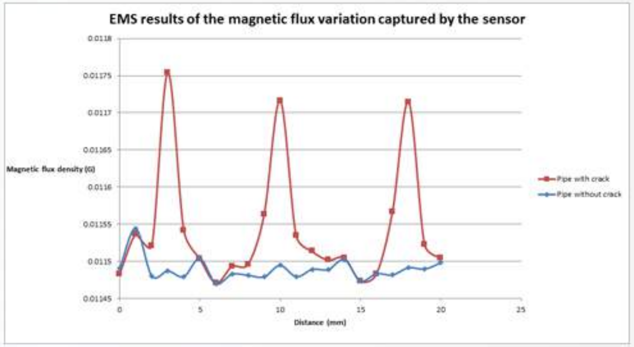


Figure 19: Magnetic flux captured by the sensor in both cases pipe -with and without- defects

Pulsed Current Testing (PCT):

PCT is an advanced electromagnetic inspection technology used in detecting flaws and corrosion in ferrous materials, typically hidden under layers of coating, fireproofing, or insulation. The PCT technique uses repetitive pulses of short time duration instead of the sinusoidal signal with single frequency. The Fourier transformation of a square pulse contains a series of different frequency components. Since the penetration factor depends on the frequency, the diffusion of the generated eddy currents covers a wide range of thickness.

High frequency components penetrate less and can be observed firstly, while lower frequency components reach deeper thickness. The probe used for PCT testing utilizes a coil to generate eddy currents in the metal, while the generated magnetic field is detected by a sensor (coil sensor, Hall sensor, etc.)

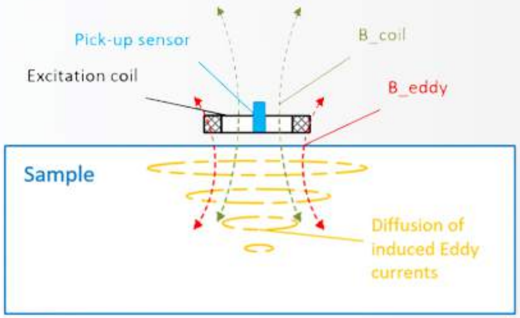


Figure 20: Pulsed current testing principle [5]

Example 4: PCT Inspector

In the following example, a PCT probe is used to detect the defect on a multi layer object shown in the Figure 21. The tested object is made of (from top to bottom): Mitsubishi plastics E002, Si Rubber, aluminum and stainless steel. The aluminum layer contains the defect (red body).

The whole 3D model is built inside SOLIDWORKS. The PCT probe is composed of two coils; an emitter pulsed coil and a receiver coil. The emitter is excited by a short time voltage pulse. When the voltage pulse ends, the induced voltage of the receiver coil is measured.

The Transient module of EMS is used to compute and visualize the electromagnetic quantities in the time-varying domain. Figure 22a) and 22b) show the eddy currents density in the tested piece, respectively without and with crack. The plot in Figure 22b) demonstrates a discontinuity because of the zero eddy currents in the cracked zone.

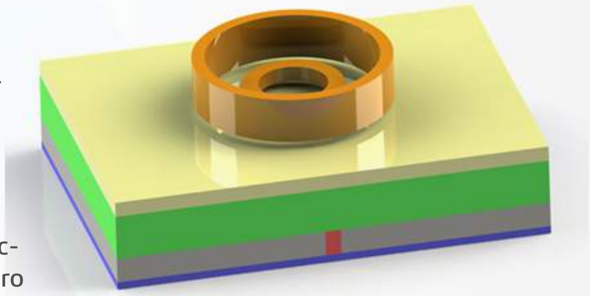


Figure 21: 3D model of the PCT Inspector

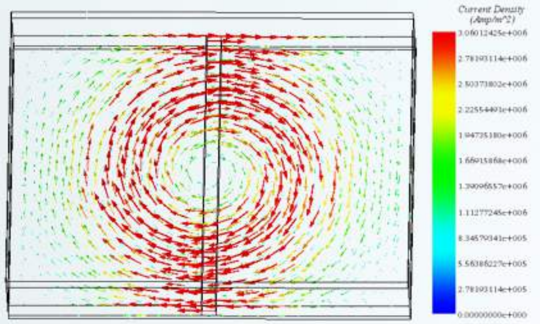


Figure 22a: Eddy current distribution in case of object without crack

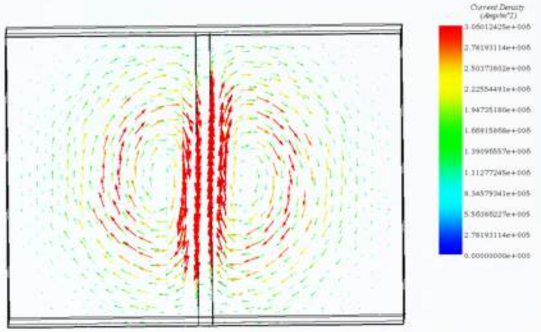


Figure 22b: Eddy current distribution in case of object with crack

Pulsed Current Testing (PCT):

Figure 23 shows the voltage pulse injected into the emitter coil. The pulse width is 2e-3 s. Figure 24 demonstrates the calculated induced voltage of the receiver in both cases with and without defect starting t=2e-3 s which is the time of switching off the pulse. It shows that the induced voltage in the receiver is a bit higher in the presence of the defect. Figure 25 illustrates the absolute difference between both induced voltages. This measured quantity helps to detect the crack and estimate its dimensions.

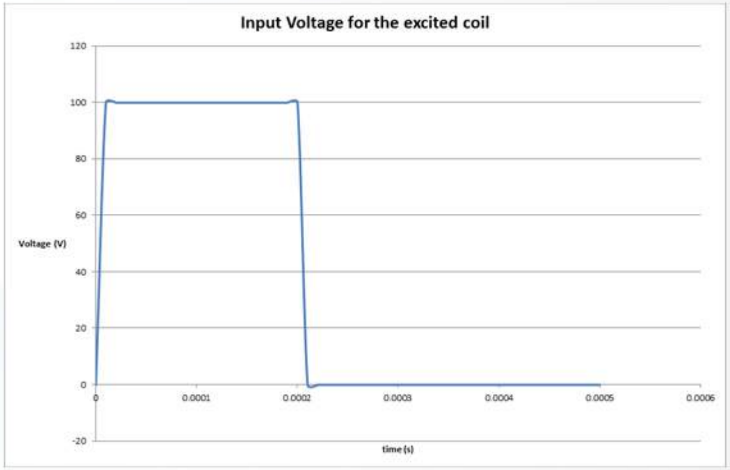


Figure 23: Excitation voltage of the emitter coil

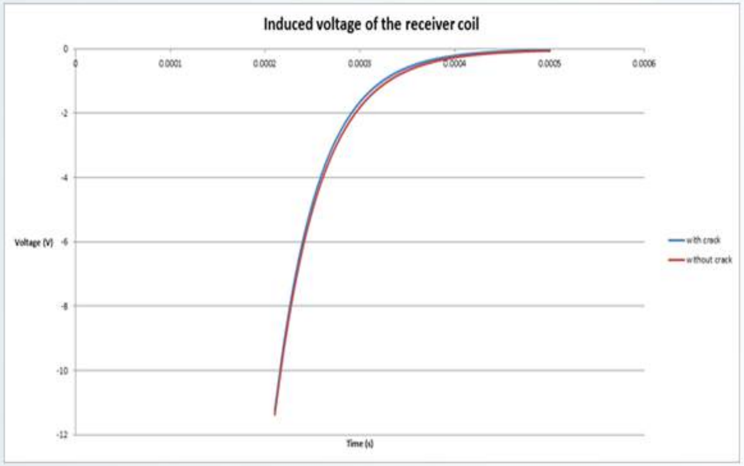


Figure 24: Induced voltage for both case of the tested object

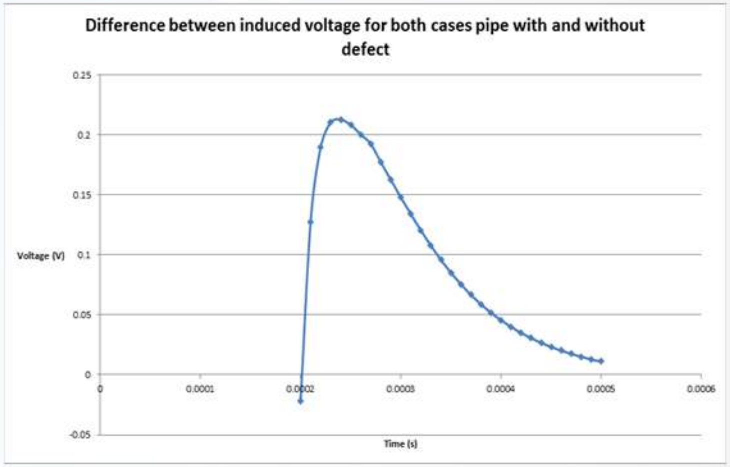


Figure 25: Absolute induced voltage

Eddy Current Thermographic Inspection:

Infrared thermography (IRT), as one of the Non-Destructive Testing (NDT) methods, has been widely used recently in various fields such as automobile, spaceflight, petrochemical industry, etc. Eddy current thermography, as its name suggests, is an IRT technique based on the eddy current as the source of heat. In this method, the tested material is exposed to an alternating magnetic flux generated by a solid or stranded coil. The magnetic flux creates eddy currents which will result in the heating of the material. An infrared (IR) camera is used to capture the thermal response of the tested object. Analyzing the camera images can give information about the defects in the tested material. This technique is characterized by a wide scope application, a high detection speed, a contactless inspection, etc.

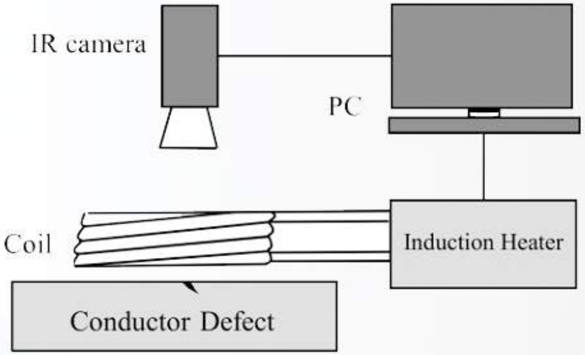


Figure 26: EC thermograhic inspection principle [6]

Example 5: EC thermography model [8]

This example consists of spiral coil enrolled around a U-shaped ferromagnetic core. Both are used in inspecting a defected structural steel. By passing a high frequency current in the coil, a time-varying magnetic flux density is generated. The magnetic flux conducted by the ferromagnetic core reaches the tested object where an eddy current is induced. The eddy currents cause the heating of the object due to the Ohmic losses. Interpreting the thermal response of the steel plate can help to determine the crack location. Figured 27a) and 27b) show, respectively full and cross section view of the 3D simulated model built with SOLIDWORKS.

AC Magnetic module coupled to transient thermal analysis is used to study the case. The coupling is entirely established inside EMS and on the same model. There is no export/import data which can assure more reliable results. Both Electromagnetic and thermal results will be computed.

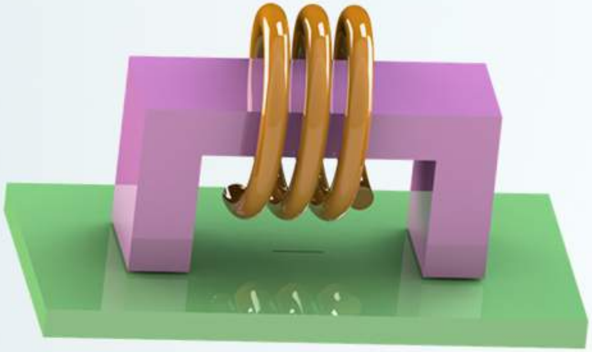


Figure 27a: Full model of the simulated EC thermgraphy example

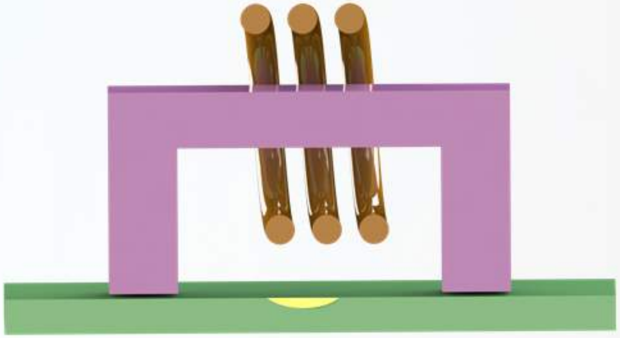


Figure 27b: Cross section view of the simulated EC thermography example

Eddy Current Thermographic Inspection:

The time varying magnetic flux density, generated by the coil, creates an eddy current in the skin depth region of the tested piece. Figures 28 and 29 show the induced currents which are circulating on the surface of the plate. The skin depth is very small in this study case due to the high frequency of the excitation current (155kHz). It is inversely proportional to the frequency, the electrical conductivity and the relative permeability of the material. As have been demonstrated in the previous techniques, the eddy currents are concentrated in the crack region.

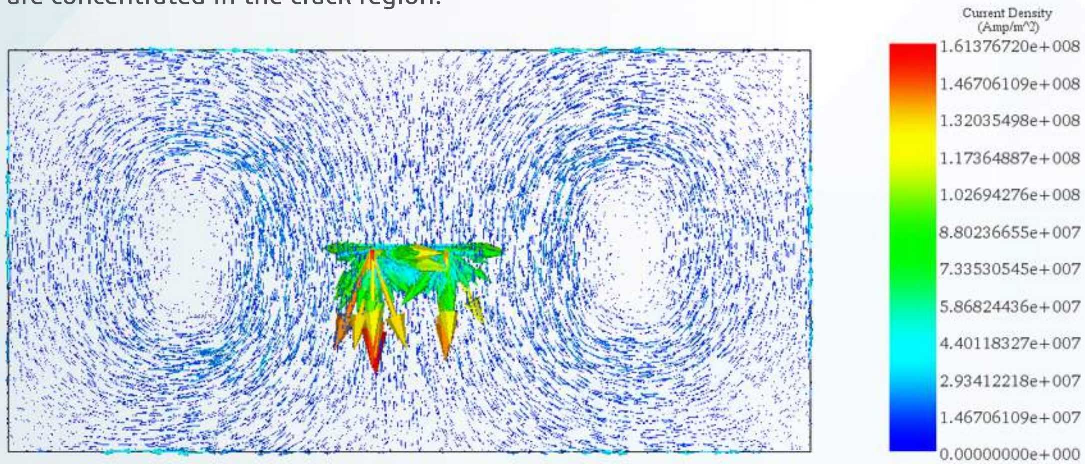


Figure 28b: Planar view of the eddy currents distribution in the tested plate

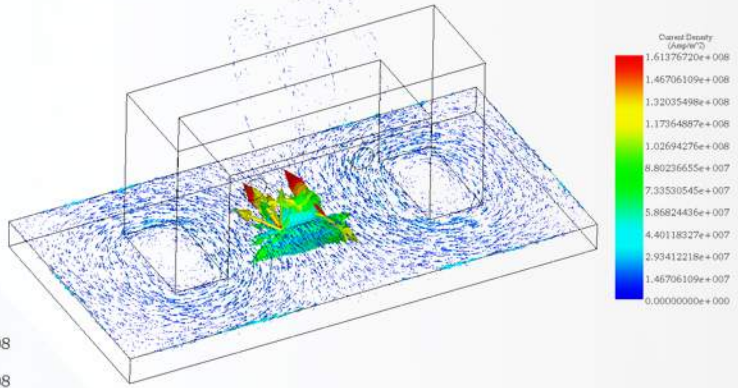


Figure 28a: Isometric view of the Eddy currents distribution in tested plate

These currents will cause the heating of plate by Joule effect. The regions with higher eddy currents will get the higher temperature. Figure 29 demonstrates the thermal response of the investigated piece after 500 ms. it shows a high spot temperature in the middle of the plate which represents the crack zone. In the real case, an IR camera captures this response and analyzes it to give information about the defect. In Figure 30, the temperature distribution is plotted in the crack zone after isolating it.

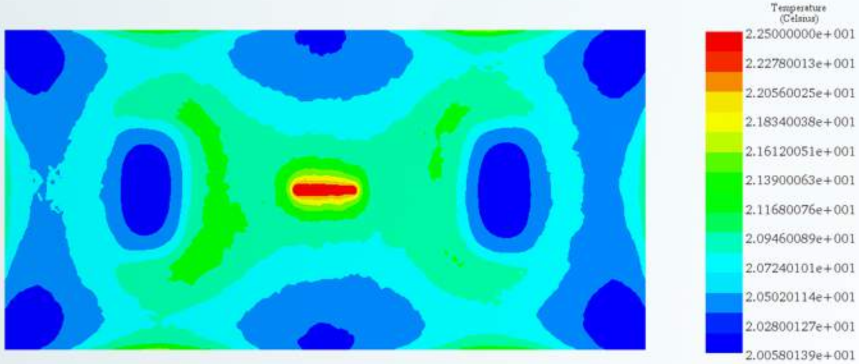


Figure 29: Planar view of the temperature distribution in the plate after 500 ms

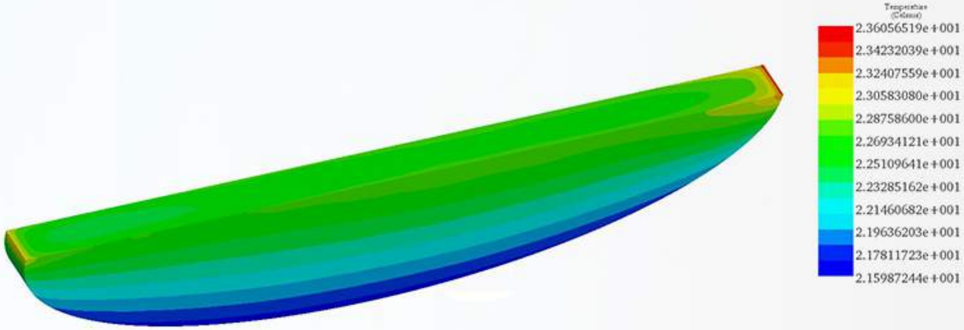


Figure 30: Temperature distribution inside the crack region after 500 ms

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