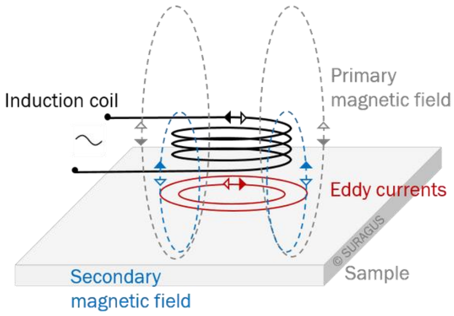
Eddy Current for Additive Manufacturing Physics

Eddy Current testing (EC) is a well-established and standardized non-destructive testing (NDT) technique used to detect surface and near-surface defects such as cracks. The working principle of the sensor is based on coil induction and magnetic field counteraction.

When one puts an AC current inside a coil, it generates an alternating magnetic field along the coil axis. If the coil is close to an electrically conducting material, an eddy current loop appears in it, which creates a second magnetic field opposite to the one generated by the coil as described by Lenz's law. This induces changes in amplitude and phase in the total current in the coil and these can be detected and measured.



EC is widely used in industry to control and certify the quality of electrically conducting parts. For non-ferromagnetic metals, the presence of a defect (discontinuity or heterogeneity) causes a reduction and a redistribution of the eddy current loops. This has consequences on the coil's inductance and resistance, causing a change in the signal. The underlying process is more complicated with ferromagnetic metals as it results in a coil inductance increase.

Typically, the signal variations are traditionally displayed on a 2D graph called the impedance plane where the x- and y-axis correspond to the real and imaginary parts of the impedance, or in other word, the resistive and the inductive parts.

Measuring these variations is achieved with bridge circuits. The actual EC module consists of an electronic board and a probe. The probes are composed of coils generating an alternating magnetic field. The electronic board produces the alternating current and demodulates the signal.

The EC signal depends on multiple factors like the material magnetic and electric properties, the geometry of the scanned object, the probe conception, and the excitation frequency. Some of these parameters are linked with the penetration depth, given by the following equation:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Where δ is the standard depth penetration in mm, f is the excitation frequency of the coil in Hz, μ is the magnetic permeability ($\mu = 1$ for non-magnetic materials) and σ is the electrical conductivity in MS/m (mega Siemens / meter).

This formula links the penetration depth, the material properties (conductivity and magnetic permeability) and the coil excitation frequency. An excitation frequency decrease leads to an increase of the penetration depth.

The scanning technology based on EC maps each location on the analysed object to a signal point. These are used to produce an encoded signal (or map) of a region of interest and requires a one-axis (resp. two-axis) encoder. The critical factor in this process is the number of acquired points N acquired at frequency f for a certain time Δt. During this time, the sensor moves over distance d while moving at a constant speed v. The variables are related to each other as follows:

$$f = \frac{N}{\Delta t} \ [Hz]$$

$$v = \frac{d}{\Delta t} \ [mm/s]$$

Hence, the number of points per distance unit is calculated with the following relation:

$$Point\ spacing = \frac{d}{N} = \frac{v}{f} \ [mm]$$

Logically, the number of points per millimetre is optimized by increasing the acquisition frequency and reducing the scanning probe speed. A standard example shows a “number of points per distance” of 2.5 [pts/mm] with an acquisition frequency of 375[Hz] and a scanning speed of 150 [mm/s], leading to a point spacing of 0.4 [mm].

Note: It is important to notice the difference between the *excitation frequency of the coil* and the *acquisition frequency* (or acquisition rate) of the signal.