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Open-ended Coaxial Sensor Simulation for NDT applications

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Abstract- *In this work we will present a numerical modelisation of an open-ended coaxial sensor by electromagnetic simulation software HFSS (High Frequency Structure Simulation). This sensor will be used for surface defects detection in conducting materials and volumic defects detection in dielectric materials. It is based on near field microwaves techniques. The crack in surface material create a variation in resonant frequency, this effect will be used non-descriptive testing application (NDT). This sensor model is established to work in a frequency of 24 GHz, it has characterized using HFSS software for 3D Ansoft structures Design. The representation of all basic elements in the structure is called "MESH". The software calculates a solution at some positions of the MESH and then reconstitutes a global solution in matrix form. This sensor is able to detect defects in the order of µm and surface depths of an aluminum plate used for deferent depth values and deferent shapes, Measuring electromagnetic properties (Complex permeability, complex permittivity, reflection coefficients, Etc.) for the evaluation of materials.*

Keywords: Sensor, microwaves, numerical simulation, non-descriptive testing (NDT), Ansoft-HFSS.

1. INTRODUCTION

Due to their various attractive features and excellent advantages, microwaves sensors have attracted attention in both theoretical research and engineering applications over the past decades. Microwave sensors are used in an increasing number of applications such as biomedical and non-destructive diagnosis and testing. Many new measurement problems have been solved by various types of microwave sensors [1]. Those sensors have therefore become more and more common in the various sectors. Microwave sensors are used in industrials applications distance measurement, motion, shape, and particle size, but the largest group of applications is related to the properties of the material. [2]
Crack monitoring is essential to ensure the safety of structures. At present, many approaches have been developed for the monitoring of cracks, such as ultrasonic methods [3,4], Acoustic emission [5], infrared thermography [6], impact-echo large area electronics, etc. All those techniques mentioned above show a good crack detection performance, but they present many difficult to apply in practical engineering due to installation difficulties and vulnerability in the long-term hard environment. Recently, optical fiber detection technology, [7] Michelson white light interferometer and Brillouin scattering were studied to detect cracks. The majority of the fibers are silica fibers that are fragile, which facilitates the breakdown of real applications, and only small cracks can be monitored. Therefore, the fragility of the silica fibers limits application. [7] In order to overcome this drawback, the

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coaxial cable, which has a high elongation rate and functions similarly as an optical fiber, because they share the same fundamental physics governed by the same electromagnetic (EM) theory, has been attempted to monitor the cracks. [8]

The coaxial probe method is a method of microwave measurement that allows the reflection coefficient at the probe terminal to be measured deep down the probe terminal to the measured materials in order to capture the complex microwave permittivity of the materials. This technique not only has the advantages of being non-descriptive and non-invasive materials, but also the ability to measure bandwidth and ease of sampling. As a result, this method has been widely applied to measure the permittivity of microwave complexes of dielectric materials and composites.

There are several applications of open-ended coaxial cable sensors that can be applied in Non Destructive Testing (NDT), Characterization of dielectric and composite materials, fluids. Other applications such as the medical field and quality control of Agri-food products.

2. THEORETICAL STUDIES

2 .1. NDT Microwave

The MCND techniques (MNDT) allow measuring the following parameters: the reflection coefficients, the coefficients of transmission, dielectric constants, loss factor, complex permeability as a function of frequency (microwave) and temperature. These measured parameters can be related to interesting material parameters (eg defects, in homogeneities, moisture content, etc.) by appropriate modelling and calibration. Methods (MNDT) classified several microwave in two categories:

- Free-space methods operating in the far-field region using point-focusing antennas.
- Waveguide methods operating in the near-field region that use open-ended coaxial lines, rectangular waveguides, micro-ribbon lines, and probe cavity resonators. However, in waveguide methods, it is necessary for the composite material to be in close contact with the probe. So these methods are not without contact. [2]

2.2. Application of microwaves coaxial cable probes

In 2007: V. K. Ivanov et al determine the permeability of the dielectric materials, by a probe in the form of an open-ended coaxial line isolated from the medium probed by a thin layer. They developed an integral wave admittance model adapted for the calculations of this probe in the form of a series with the number of terms corresponding to the number of higher modes excited in its opening. [9]

Michael J. Kuhn et al (2010) perform the Measurements of the open-ended coaxial probe for the detection of breast cancer. They simulated and experimentally tested a coaxial probe measurement system and use to distinguish between normal and cancerous tissues of breast tissue. The system uses a probe has available components, including an agilent 8363B network phase (PNA) and a dielectric. Instead of the agilent software, three-dimensional calibration technique, they have proposed a calibration of four over a frequency range of 3-17 GHz for more than robust measurements of the complex permittivity. Experimental results on tissues humans and natures non-homogeneous biological tissues and illuminate the dependence of the complex permittivity on the temperature. Basing on differences and observed variation in the complex permittivity between normal and cancerous breast tissue in the literature through this frequency, then, they propose a technique that uses a neuron network where several measures are taken into account in the decision if the tested fabric is cancerous yes or not. The simulation results using Ansoft HFSS are provided here and show the potential of microwave diagnosis of breast cancer. [10]

Thereafter, in 2011: Linsheng Liuet Yang Ju use a non-standard evaluation method Effective Destructive (NDE) to Measure Pipe Wall Refinement (PWT) at a Distance to using microwave. A vector network analyzer (VNA) as a line sensor coaxial transmitter-receiver (T & R), we reemployed in the experiment for generate microwave signals propagating in the room, whose frequency has been carried from 14.00 to 14.20 GHz. A brass tube with an internal diameter of 17.03 mm, thickness of wall of 1.0 mm, length 2.0 mm, and 6 joints having a length of 17.0 mm and a pipe refinement from 0% to 60% of the wall thickness were measured. The waveguide tubular radio waves, after construction Assessments, evaluation of PWT have been realized. Comparison of the evaluated results obtained are used a model with the individual dimensions in the joints, the evaluation is less than 0.05 mm, which represents less than 0.294% of what indicates the importance of assessing the accuracy.[11]

K.YOU and Al (2013) present an experimental study for the determination of moisture content (mc) in kernels in a range of (9.5% to 26%), using an open-ended coaxial probe, the coaxial probe was manufactured by empirical polynomial models. They are developed to predict the gravimetric moisture content of rice based on reflection coefficients measured using a vector network analyzer. The relationship between the coefficient of reflection and relative permittivity was also created using a method of regression and expressed in a polynomial model whose model coefficients were obtained by adjusting the finite element simulation data. In addition, Experimental facilities were shown as well as the rice grain sample holder designed is unique. The measurement of individual rice grains in this study is more accurate by ratio to the measurement in conventional mass rice grains because the random air gap present in bulk rice grains is excluded. [12]

Then, in Yang, S. H et al (2013) use an open coaxial line sensor and two microwave frequencies to detect the surface cracks of film-coated metals. The detection of superficial cracks is important to ensure the safety of metal structures. The electromagnetic wave technique can detect metals coated with surface cracks; so much research on this method has been conducted. However, the method for determining the optimal frequency for the detection of surface cracks has not been introduced. Detection of surface crack using an open-ended coaxial voltage detector with frequencies ranging from 14 to 18 GHz. Low frequencies increasing or decreasing the reflection coefficients have been found, could be explained according to the capacity model of microwave reflection. [13]

a. Defect detection system

The defect detection system includes a network analyzer, an open-end coaxial cable sensor and an aluminium plate contains defect with various depth (1 mm, 1.5 mm and 2 mm). The probe (sensor) reflects the permittivity of the material at the end of the probe, as shown in Figure 1.

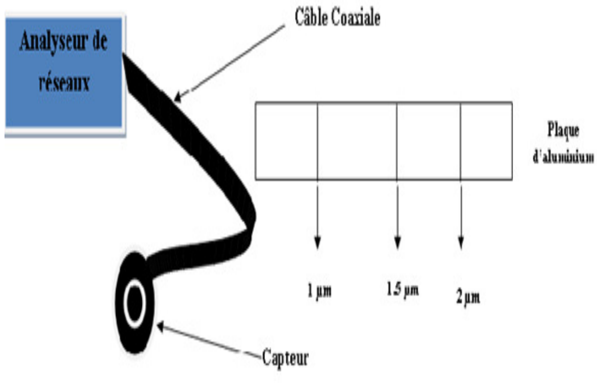

Figure 1. Measurement system and detection of defects.

b. Equivalent circuit of a coaxial probe and impedance model

A coaxial probe contains two conductors that conduct an insulation that forms a capacitance plus a load.

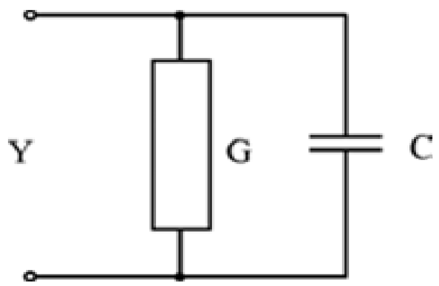

Figure 2. Equivalent circuit of a probe. [14]

A number of different models have been proposed to relate the impedance to the T plane with the dielectric constant of the material tested.[15] The models most commonly used are the grouped parameter model, the slightly enlarged version of the grouped parameter model, the antenna model, the virtual line model and the rational function. It has been demonstrated that, given a sample of At least twice the thickness of the outer diameter of the probe, the Markowitz model is sufficiently accurate. As shown in figure 2.

c. Type of defects

The fault parameters depend on the type of defect used there are several types the most uses two rectangular or circular forms, in note work is interested on the rectangular defect. The following figure shows the two types of faults. (L) represented the fault length and (w) the fault width, (D) fault diameter.
The defects create in two 304L series stainless steel aluminium plates; two types of defects were created in these two plates.

- **Circular defects**

Circular defects of different depths from 1 mm to 2.5 mm, defect section S = 3 ° in a dimming plate of 150 mm x 120 mm and 4 mm duster.

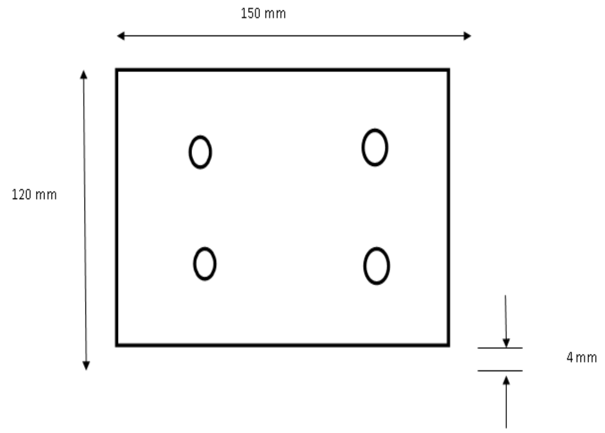

Figure 3. Circular defect of deferent to depth.

- Line faults

Line defects of deferent depths from 1 mm to 2.5 mm, the defect width is 5 mm, in a depot of dimmable aluminium plate 150 x 120 x4 mm^3

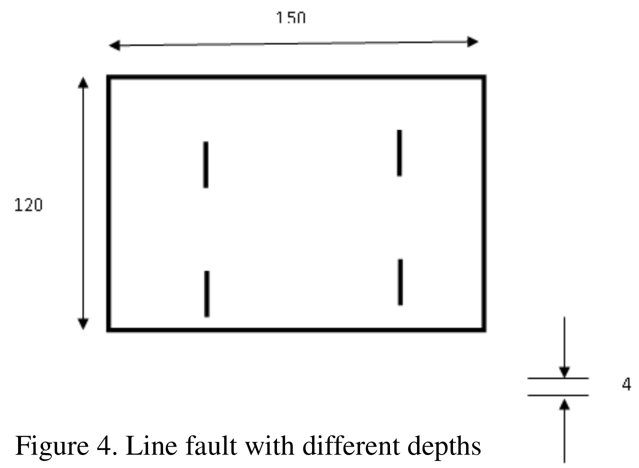

Figure 4. Line fault with different depths

3. Simulation Results

3.1. Sensor structure a Vacuum

Sensor dimensions A = 0 B = 3 mm Sensor Width 14.8 mm. The materials used for the sensor configuration, Copper R = 1 mm and length of 14.8 and R = 2 mm and length 14.8 mm Teflon R = 1.5 mm and length of 14.8 mm Copper R = 1 mm and length 14.8 and R = 2 mm and length 14.8 mm Teflon R = 1.5 mm and length 14.8 mm.
The following figure shows the 3D structure of the sensor has been studied by the HFFS simulation software.

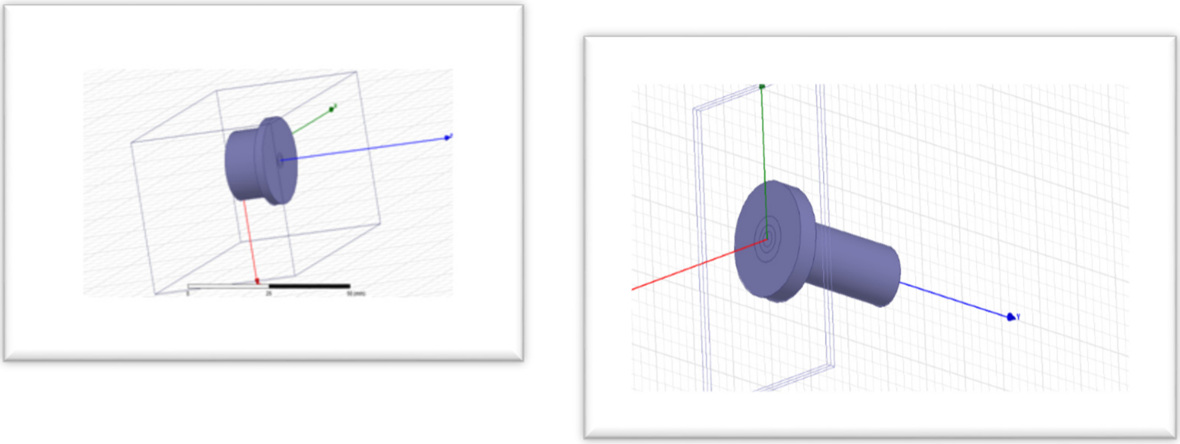

Figure 5. Sensor structure has been studied in 3D

3.2. Effect of dielectric materials types on the reflection coefficient (S11)

The following table shows the values of the permittivity and the resonance frequency of each dielectric materials used.

Dielectric Materials	Relative Permittivity	Resonance Frequency (GHz)
Plexiglas	3.4	21.1900
vacuum	1.0	24.9200
Mica	5.7	22.8800
Glass	5.5	22.8900
Teflon	2.08	22.0300
Polyethylene	2.25	22.9200

The following figure presents a reflection coefficient of different dielectric materials. The results obtained show that the types of materials affect the resonance frequency.

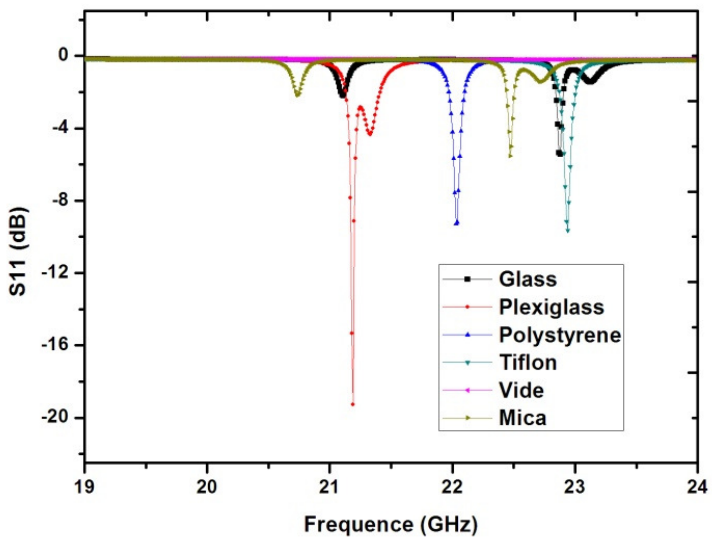

Figure 6. Variation of reflection coefficient (S11) depending on dielectric materials types.

3.3. Effect of Variation of Reflection Coefficient (S11) on Depth of Defects

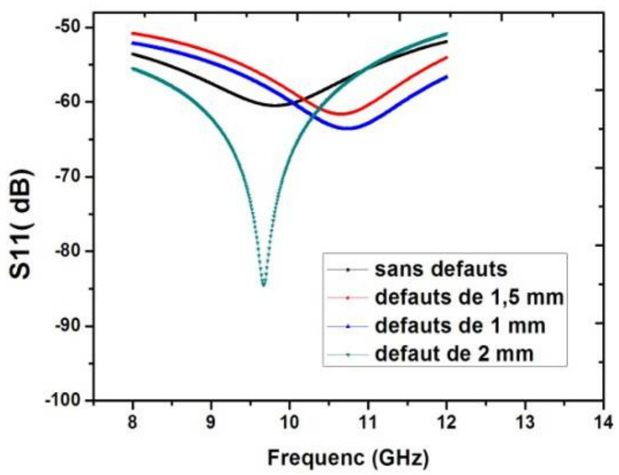

Figure 7. Variation of reflection coefficient (S11) depending on the depth of the defects

This figure shows that the defect thickness is proportional to the module of reflection coefficient and inversely proportional to the resonance frequency.
In the case of absence of defect, the reflection coefficient is in the order of -65 dB at the frequency of 9 GHz. Defaults vary from 1 mm to 2 mm, the module of the reflection coefficient increases from 65 dB to 86 dB. The resonant frequencies varie from 9.3 GHz to 10.5 GHz.

4. Conclusion

In this paper, we performed a numerical modelisation of an open-ended coaxial sensor using HFFS-3D software. To simulate the characteristics of a vacuum sensor by HFFS we begin to schematize the real structure that we wish to simulate (the choice of materials, dimensioning of the structure). After that, comes the step of choosing border conditions. The numerical simulation allowed us to calculate the reflection coefficients that characterize this sensor. We then studied the sensitivity of reflection coefficient to the depth of defects. We have found that each time the increased defect depth leads to an increase in reflection coefficient.

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