Detection of defects using Open-ended coaxial probe

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***Abstract*— This paper presents a numerical simulation of an open-ended coaxial sensor using electromagnetic simulation software HFSS (High Frequency Structure Simulation) for cracks detection in surface of conducting metals. This sensor is based on near field microwave techniques. The detection is determinate by the variations induced by cracking resonance frequency for non-descriptive control (NDT). The simulation is established for a frequency of 24 GHz without charge.**

We have characterized this sensor using Ansoft-HFSS software for 3D Ansoft Designer structures. The representation of all the 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 deferring depth value and deferring shape, Measuring electromagnetic properties (Complex permeability, complex permittivity, reflection coefficients, Etc.) for the evaluation of materials.

***Keywords*— Sensor, microwave, numerical simulation, non-descriptive control (NDT), Ansoft-HFSS.**

1. INTRODUCTION

Due to their various attractive features and excellent advantages, microwave 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]. These 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], Acoustic emission [4], infrared thermography [5], 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 [6], 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 applications [6]. In order to overcome this drawback, the 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 attempting to monitor the cracks [7].

2. THEORETICAL STUDIES

Detection of defects using Open-ended coaxial probe is based on reflection method, its non-resonant method type. In this method, the sample under test is introduced into a certain position of a transmission line, and so the impedance loading to the transmission line is changed. The properties of the sample are derived from the reflection due to the impedance discontinuity caused by the sample loading.

A. Defect detection system

The defect detection experimental system set-up consists of a network analyzer, an open-end coaxial cable sensor and an aluminum 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.

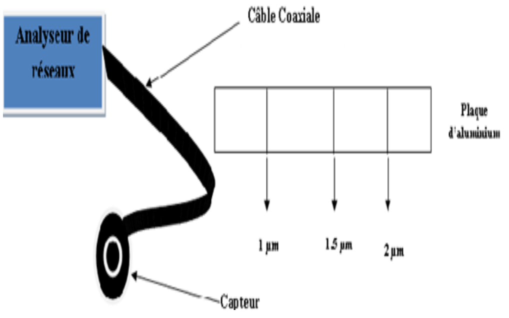

Fig.1. Measurement system and detection of defects.

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.

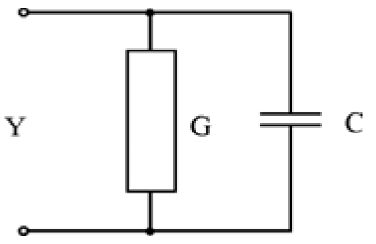

Fig.2. Equivalent circuit of a probe. [8]

A number of different models have been proposed to relate the impedance to the T plane with the dielectric constant of the material tested.[9] 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 Marcuvitz model is sufficiently accurate. As shown in figure 2.

The reflection coefficient is determined according to combinations of the coaxial probe, the specimen and a thin film is placed between them, this thin film becomes another capacitor. In this case, the reflection coefficient at the end of the coaxial probe is expressed as:

$$S_{11} = \frac{1 - j2\pi fG[C_f + C(\varepsilon_f) + C + C(\varepsilon_s)]}{1 + j2\pi fG[C_f + C(\varepsilon_f) + C + C(\varepsilon_s)]} \qquad (1)$$

Where: G, C and C_f are the characteristic impedance of the coaxial probe, the capacitance of the specimen and the capacitance of the film respectively. ε_s and ε_f are the complex relative permittivity of the specimen and the film. f is the frequency.

In order to simplify the calculation the effect of the thin film will be neglected Then, Eq. (1) becomes

$$S_{11} = \frac{1 - j2\pi fG[C + C(\varepsilon_s)]}{1 + j2\pi fG[C + C(\varepsilon_s)]} \qquad (2)$$

The capacitances with and without the surface crack are different duo to the crack includes an air space which does not exist without the surface crack. So the surface crack can be detected by comparing the reflection coefficients on the specimen with and without the surface crack. Also, they are certain measuring frequencies at which the reflection coefficient is sensitively changed due to the surface crack, these frequencies can be the optimal frequencies for detecting the surface crack.

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.

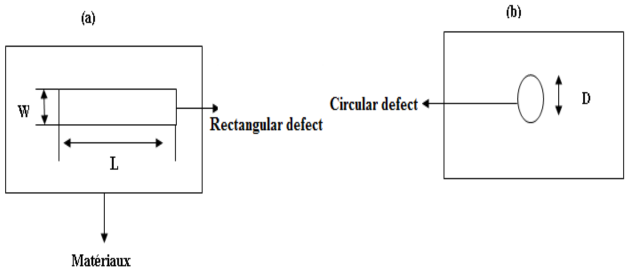

Fig.3. Types of defects a) rectangular defect b) circular defect.

3. SIMULATION AND EXPERIMENTAL RESULTS

A. *Sensor structure a Vacuum*

Figure 4 shows the 3D structure of the coaxial probe. The front sectional aperture of coaxial probe shows 1mm diameter of inner conductor (copper), 3 mm diameter of coaxial-filled Teflon and 4 mm diameter of the outer conductor. Both inner and outer conductors guide the propagation wave in the coaxial line. In addition, an 2a=11.3 mm total diameter steel flange is used to cover the total fringing field at the aperture probe. The sensor length is h_1+h_3=14.8 mm

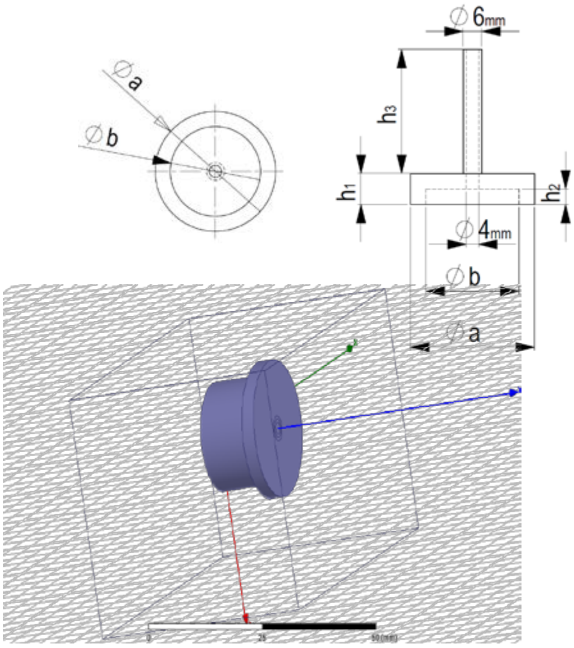

Fig.4. Sensor structure has been studied in 3D.

B. *Contact sensor structure with the Material*

B.1 Sensor structure without contact Default

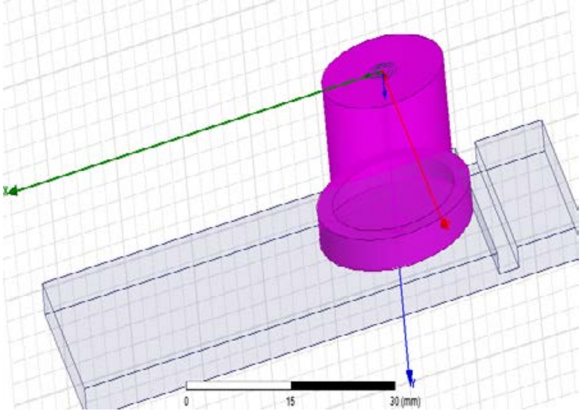

Fig.5. Sensor Structure with contact without defect by 3D HFFS

The figure below shows the reflection coefficient S11.

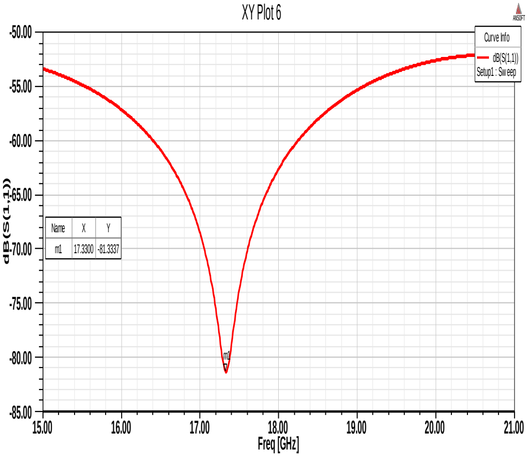

Fig.6. Reflection coefficient S11 without default

B.2 Sensor structure with contact Default

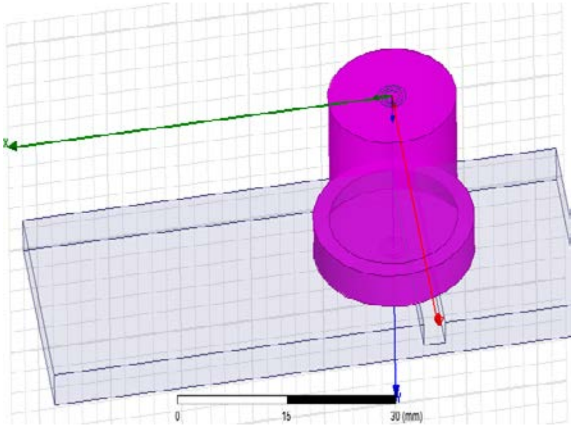

Fig.7. Sensor structure with contact with defect by 3D HFFS

The figure below shows the reflection coefficient S11.

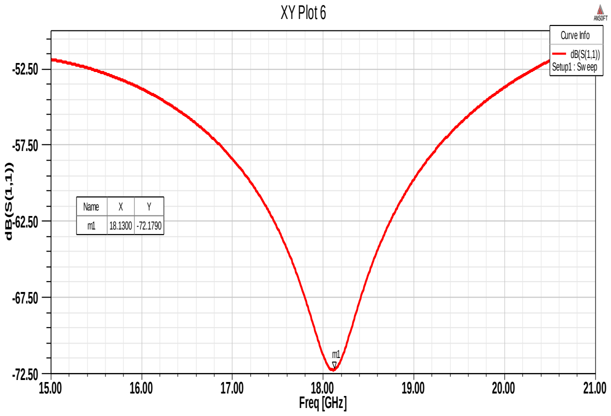

Fig.8. Reflection coefficient S11 with default**.**

B. *Effect of Variaton of Refelection Cofficient (S11) on Depth of Defects*

In the following figure, we present the effect defect depth on the reflection coefficient. The resonance frequency shifts down in frequency when the depth of the defect increases, this behavior can be explained by the change of the capacitance of the specimen due to the air space created by crack.

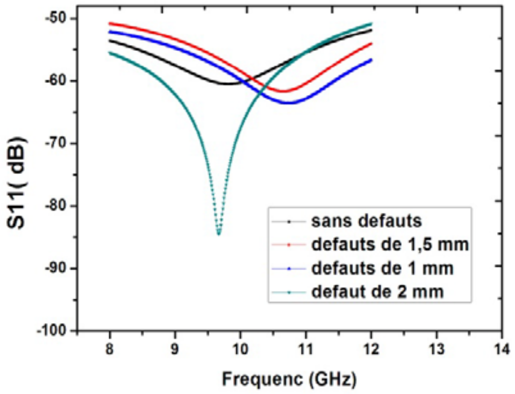

Fig.9. Variation of reflection coefficient (S11) depending on the depth of the defects.

4. CONCLUSION

In this work, we performed a numerical simulation 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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