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A NOVEL MICROWAVE FATIGUE CRACK DETECTION TECHNIQUE USING AN OPEN-ENDED COAXIAL LINE

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Abstract

Surface crack detection on metallic structures (aircraft fuselage, turbine blades and nuclear power plant steam generator tubings) is of utmost importance. The use of an open-ended coaxial line for this purpose is very attractive, because it offers advantages such as a wide frequency band of operation, small aperture (sensing) area, and excellent sensitivity.

Introduction and Geometry Consideration

Metal fatigue or failure usually begins from the surface, as it is well known in the case of aircraft fuselage, turbine blades and nuclear power plant steam generator tubings. Hence, surface crack detection on metallic structures is vital to the on-line and in-service inspections of metallic components. There are many conventional nondestructive (NDT) methods used for interrogating metal surfaces, however, each method possesses certain limitations and disadvantages. Since the late sixties there have been several researchers who have attempted using microwaves for surface crack detection on metals [1]-[3]. Microwaves are capable of interrogating surface features (perturbations) on a metallic structure and offer certain advantages, when detecting hair-line stress or fatigue cracks, such as: the sensor may or may not be in contact with the surface, the crack may be filled with dielectric materials such as paint or rust, the surface of the metal may be covered with paint or a similar compound [4,5]. The use of an open-ended coaxial line as a sensor for measurement of material properties at microwave frequencies has received considerable attention [6]-[8]. Utilizing such a sensor for crack detection is very attractive, because it offers advantages such as a wide frequency band and small aperture (sensing) area as well as superior sensitivity compared with other microwave probes. Fig. 1 shows the geometry of an open-ended coaxial probe, and its relative position with respect to a surface crack.

Fig. 1: The relative position of a crack and an open-ended coaxial line.

For the measurements presented here two open-ended coaxial line sensors were used to detect a crack with a depth of 1.2 mm and a width of 0.034 mm. In these measurements the probe scanned the metal surface, and the crack was detected when a change in the monitored signal occurs. A simple reflectometer network was used to measure the voltage associated with the reflected signal form the metal surface. Fig. 2 shows the results of an experiment, performed with a coaxial line with an inner conductor radius of 1.6 mm and an outer conductor radius of 9.55 mm filled with Teflon at 12 GHz. When the coaxial sensor is probing the non-cracked portion of the metal surface, a relatively constant voltage value is detected (short circuited coaxial line). However, when the crack is in the vicinity of the edge of the inner conductor it causes a sharp increase in the detected voltage value, i.e. the crack has been detected. The same phenomenon occurs as the crack reaches the other side of the inner conductor. Beyond this point the detected voltage value reverts back to the short circuit value. A second experiment was conducted on the same crack and at the same frequency, but with a teflon filled coaxial line whose outer conductor radius was 1.8 mm and its inner conductor radius was 0.425 mm. The result of this experiment is shown in Fig. 3. In this case only one peak is observed. This is due to the fact that the inner conductor dimension is smaller than in the previous case, and the two distinct peaks have become combined with each other.
The signal voltage-to-background voltage ratio is that much smaller cracks may still be detected at low microwave frequencies.

The theoretical formulation is based on the analysis of the fields radiating from an open-ended coaxial line. Depending on the size of the coaxial line and the operating frequency traveling/radiating fields or quasi-static fields are considered. Subsequently, a solution for the reflected fields from a shorting conducting surface is obtained. The solution is based on forcing the boundary conditions at the interface between the coaxial aperture and the conducting surface. Finally, this solution is modified to include boundary conditions due to the presence of a crack. The existence and the influence of higher order modes at the crack/coaxial aperture interface, are also considered.

References