Modeling of surface hairline-crack detection in metals under coatings using an open-ended rectangular waveguide

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A surface-breaking hairline crack or a narrow slot in a metallic specimen when scanned by an open-ended rectangular waveguide probe influences the reflection-coefficient properties of the incident dominant mode. Subsequent recording of a change in the standing-wave pattern while scanning such a surface results in what is known as the crack characteristic signal. Since microwave signals penetrate inside dielectric materials, this methodology is capable of detecting cracks under dielectric coatings of various electrical thicknesses as well. To electromagnetically model the interaction of an open-ended rectangular waveguide with a surface-breaking hairline crack under a dielectric coating, the dielectric-coating layer is modeled as a waveguide with a large cross section. Thus, the problem is reduced to a system of three waveguides interacting with each other while the location of the crack is continuously changing relative to the probing waveguide aperture (a dynamic scanning problem). An analysis of modeling the dielectric-coating layer as a dielectric-filled waveguide with a large cross section is given, and its comparison with radiation into an unbounded medium is presented. For obtaining the reflection coefficients of the dominant and higher order modes, the electromagnetic properties of the probing waveguide-dielectric-coating layer junction and the dielectric-coating layer-crack junction are separately analyzed. For each junction, a magnetic-current density M is introduced over the common aperture. Subsequently, the junction formed by the two respective waveguide sections is separated into two systems. A numerical solution employing the method of moments is obtained, and the properties of the junctions are expressed by their respective generalized scattering matrices. Consequently, the generalized scattering matrix for the total system can be evaluated. The convergence behavior of the system is studied to determine an optimal set of basis functions and the optimal number of higher order modes for a fast and accurate solution. Finally, the theoretical and measured crack characteristic signals are compared.

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