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Models and Classification Procedures For Ultrasonic Inspection of Holes for Fatigue Cracks

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ABSTRACT

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As non-destructive inspection problems become more challenging, the need for improved modeling techniques, to interpret raw signals, and for automated classification approaches to improve inspection accuracy and time of inspection, has become evident. In this Dissertation, modeling and automated classification were applied to a particular class of inspection problems, namely, the ultrasonic inspection of C-141 weep holes and rib clip holes, to gain significant progress in the inspection procedures.

Two types of fatigue cracks have been observed to emanate from weep holes, top cracks which emanate upward and bottom cracks which propagate downward toward the wing surface. Due to constraints on the placement of transducers, special ultrasonic inspection techniques were developed for detecting and sizing such cracks. An improved bottom crack detection technique was developed which examines the variation in A-scan signals as the transducer is incrementally moved across the hole to detect superimposed signals independently from the pulse shape. A neural network assisted, automated inspection technique for bottom and top crack detection of weep holes was implemented. The value of modeling, in-field demonstration, parametric studies, and probability of detection validation is demonstrated. The performance of the automated procedure was found to exceed prescribed requirements and inspection over the alternative procedure of viewing C-scan images. Using ray analysis, analytical models and boundary element method (BEM) simulations to characterize signals from top notches, a methodology for sizing was determined.

In addition to the empty hole configurations, three additional hole configurations were examined for detection of top cracks. Using a BEM model for the scattering response to a transducer signal incident on a fluid-filled cavity with a notch, a viable ultrasonic inspection strategy was developed. Analytic models were derived for a plane wave incident on a cylindrical hole with an elastic layer to evaluate the effect of a polyurathane lining on the surface of weep holes. A BEM model was applied for the scattering response generated by a transducer signal incident on a cylindrical hole with a radial notch and an elastic insert. Using model comparisons with experimental results, the interface condition was characterized, and a viable approach to inspection was developed.

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LIST OF ABBREVIATIONS

a = radius of cylindrical hole
b = radius of cylindrical interface between hole and elastic layer (Chapter 6)
b = length from crack tip to along path tangential to hole (Chapter 4)
c, c_L, c_T = phase velocity, of longitudinal wave, of shear wave
$c_r, c_{r'}$ = phase velocity of Rayleigh wave, 'leaky' Rayleigh wave
d = diameter of cylindrical hole
h = annulus (layer, lining) thickness
k, k_L, k_T = wave number, longitudinal wave number, shear wave number
l, l_n = length of notch / crack
n, m = angular wave numbers
r = radial location
s = arc length on cylindrical hole
t = time
$\mathbf{s}, \mathbf{t}$ = tractions
$\mathbf{u}, \mathbf{v}$ = deflections
w_n = width of notch
x = location variable in x-axis direction
y = location variable in y-axis direction
$\mathbf{G}$ = traction system matrix (from BEM derivation)
$H_n^{(1,2)}$ = Hankel functions
$\mathbf{H}$ = displacement system matrix (from BEM derivation)
J_n, Y_n = Bessel functions
K_n, K_t = interfacial stiffness in normal and tangential directions
$\mathbf{M}$ = matrix representing system of equations
P = fundamental solution of 2D fluid problem
$\mathbf{U}, \mathbf{T}$ = fundamental solution of 2D elastodynamic problem, double layer kernal
∂V = boundary of domain
V, V_e = infinite elastic domain, elastic inclusion domain
α, β = non-dimensional wave numbers (longitudinal, shear)
λ, μ = Lamé parameters
λ = wavelength
μ_s = spatial signal variation measure (mean)
θ, θ_n = angular location, angular location of notch on cylindrical hole
ρ = density
τ_{ABA} = time of flight calculation (ABA path)
$\mathbf{t}$ = stress
$\boldsymbol{w}$ = circular frequency
$\boldsymbol{z}$ = non-dimensional crack length

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