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COMPUTATIONAL MODELLING OF GUIDED WAVE PROPAGATION FOR ICE DETECTION ON COMPOSITE MATERIALS

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1 INTRODUCTION

Guided waves (GW) are an efficient non-destructive tool in inspection and fault detection of elongated structures. Due to the special characteristics of composite materials, study of guided wave propagation in them has been an interest. In the current work, application of guided waves is investigated in ice detection on composite materials. Ice accumulation is a well-known problem on wind turbines operating in cold climate regions. The accumulated ice on the blades causes various problems like reshaping the air-foil of blades, increasing drags, mechanical failure due to higher loads, undesired vibrations, *etc.*[1,2,3]. These problems cause the performance of wind turbines to drop up to 30%[4]. In this paper propagation of guided waves in composite materials to develop an accurate ice detection system is studied using a computational model.

2 COMPUTATIONAL MODEL

The importance of finite element (FE) model is to provide a method with reasonable accuracy to predict the results for several number of scenarios with lower cost comparing to experimental work. The geometry is an 8 m long composite plate which the layups are homogenized by calculating the mean stiffness value of the laminate. The model is time-dependent and the excitation is performed by a transient force applied to one node. The displacement field is the displacement of the nodes in each element and the assumptions of linear elasticity are assumed. The general equation of motion is solved later by applying Hook's law into the wave equation which material characteristics are taken into account (Eq. 1). Due to lack of information about the damping characteristics of the material, its effects are ignored from the calculations.

$$\rho \frac{\partial^2 u_i}{\partial t^2} - C_{ijkl} \frac{\partial^2 u_k}{\partial x_j \partial x_l} = f_i, \tag{1}$$

where ρ is density of the medium, C_{ijkl} are the elements of stiffness matrix, f_i is the excitation force and u_i is the displacement. Since one aim of this study is to investigate propagation of waves in composite structure in cold climate conditions, the effect of temperature has to be taken into account. A Signal stretch method with the mode decomposition is used to handle the effects of temperature on the received signal where the signal is stretched using two stretch factors (Eq. 2).

$$v(t, \alpha, \beta) = \sum_{i=1}^{N} A_i^s S_i^s(\alpha t - t_i) + \sum_{j=1}^{M} A_j^a S_j^a(\beta t - t_j), \tag{2}$$

where α and β are the stretch factors of symmetric and asymmetric wave modes and are obtained by calibrating the model with experimental data. Ice is modelled by changing the characteristics of a number of elements where ice is placed and new stiffness and density is calculated using Eqs. 3 and 4.

Here the stiffness matrix of the selected elements is defined as a combination of characteristics of the plate and ice.

$$\overline{C} = \frac{C_i t_i + C_c t_c}{t_i + t_c}, \tag{3}$$

where C_c, C_i, t_c and t_i are respectively stiffness matrices and thickness of laminate and ice. Same correlation is defined in order to approximate the density of the selected elements in the ice accretion zone

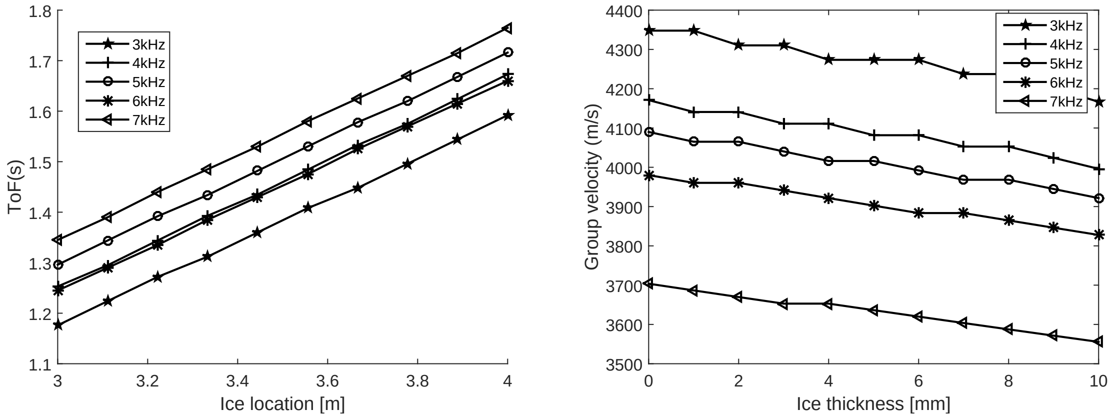
$$\overline{\rho} = \frac{\rho_i t_i + \rho_c t_c}{t_i + t_c}. \tag{4}$$

Here ρ_c, ρ_i, t_c and t_i are respectively density and thickness of laminate and ice.

The finite element model is discretized using shell elements and it is solved using COMSOL Multiphysics®.

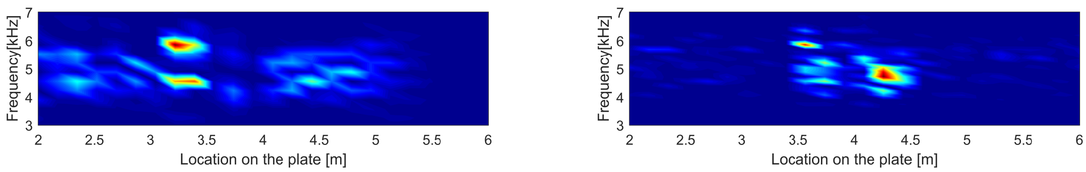
3 RESULTS

The results are shown in time, frequency and wavenumber domains. Simulations are done by applying the excitation force with different centre frequencies. Location of the ice patch can be measured by detecting the reflected waves and calculating the time of flight (ToF). As shown in Fig. 1a ToF has a linear relationship with location of ice on the plate at lower frequencies. Moreover, a comparison between the magnitude of incident wave in frequency domain for two cases of no ice and a layer of ice on the plate shows that it does not make a considerable change in the measurement nodes before and after location of ice but in the icing region higher magnitude is reached. Figure 2 shows that



(a) (b)

Figure 1: (a) Correlation between location of ice on the plate and ToF of reflected wave recorded at the first measurement node with excitation signals varying between 3 kHz to 7 kHz and (b) Variation of group velocity with respect to thickness of ice.



(a) (b)

Figure 2: Magnitude of the frequency with respect to location on the plate when 5mm thick ice is accumulated between (a) 3 m to 3.5 m and (b) 4 m to 4.5 m on the plate.

the location of ice can be found by calculating the difference in magnitude of the baseline and current signal.

Group velocity is measured using a spectrum decomposition technique[5]. Figure 1b shows the variation of group velocity of the symmetric mode by changing the thickness of the ice layer. Reduction of group velocity is presented in the simulation results for all the excitation frequencies. Approximately the same results are predicted for phase velocity due to linear relationship of phase velocity versus frequency in the examined frequency range. The model and results are published previously by the same authors[6,7,8].

4 CONCLUSION

A computational model is developed to study GWs propagating in a composite structure when ice is accreted on a composite material. Accretion of ice creates reflections which are detectable in all the measurement nodes distributed on the composite plate. The reflections are due to mode conversion from symmetric to asymmetric modes. Amplitude of reflected waves increases by increasing the thickness of ice and location of ice layer is detectable by calculating ToF of reflected waves.

Magnitude of the signal in frequency domain increases in measurement nodes which are located at the place of ice because of creation of reflections. A new approach is proposed to magnify the changes in magnitude of frequency which makes it possible to detect the location of ice on the plate.

Group (and phase) velocity of incident symmetric wave reduces when ice is created on the plate. The reduction of velocity is higher when the thickness of ice is increased and results are repeated for all excitation frequencies.

The results obtained show that application of GW is a promising method to get details about accretion of ice on a composite plate. The developed computational model, proposed criteria can be used to create novel ice detection systems for wind turbines operating in cold climate regions.

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