Fuzzy Logic based Matrix Crack Detection in Thin-walled Composite Beam under Material and Fabrication Uncertainties

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Introduction

Damage detection problem in composite structure is usually solved as an inverse problem based on the change in some measurable properties of the structure. Several researchers have studied the effect of the various modes of damage in composites on different characteristics of the composite structure. Typically these inverse problems are solved by computational intelligence methods like neural network and genetic algorithm (GA). Fuzzy logic is another useful method for modeling complex systems where uncertainty and imprecision can be important, and can be used to solve the damage detection problem. Fuzzy systems address uncertainty directly by using linguistic reasoning which is more robust to uncertainty than pure numerical reasoning [1].

Most of the earlier studies have considered the uncertainties in the form of white noise added in the measurement [2]. In this study, the damage detection system is developed based on the measurements obtained from the stochastic analysis of the thin walled structures. The matrix crack damage is modeled through the extension, bending and extension–bending stiffness matrices. The material and fabrication uncertainties are introduced using Monte Carlo simulation using the stochastic properties obtained from previous experimental work. The cross-sectional stiffness properties are obtained using mixed beam approach. The study is divided into two broad parts. First, the stochastic analysis of thin-walled composite beam with matrix cracks is carried out. Next, the fuzzy system is designed and studied for damage detection using the structural model.

Stochastic Response of the Beam

The matrix cracking is introduced using Gudmonson's model and material and fabrication uncertainties are introduced using the Monte Carlo simulation (MCS). The stochastic behaviors of material properties E_1, E_2, G_{12} and υ_{12} are obtained from the earlier experimental studies [3]. Thin walled composite beam is modeled as a single-cell box beam with outer width= 203.2 mm and outer depth=38.1 mm, having 28 plies with ply thickness=0.127 mm and a balanced layup as $[0_4/(15/-15)_3/(30/-30)_2]_s$ in all the walls. The beam length is considered as 5 m whereas mass per unit length is 6.46 kg/m.

Sometimes we may record the change in behavior of one structure from its birth itself. The results of responses with assumption that we continue to keep records of change in behavior of the same structure with increase in matrix cracking and we take the difference in change in behavior of at each crack density with respect to that of zero crack density are shown in Figures 1 and 2.

The fuzzy logic system is developed to predict damage detection system using Gaussian membership function whose mean and standard deviations are obtained from the stochastic analysis of each rules. Four rules are developed for zero, 1.0, 2.0 and 3.0. Tables 1 and 2 show the mean and standard deviations along of success rates of these rules for direct measurements and delta measurements.

Conclusion

The systematic approach is developed for predicting the matrix crack under uncertainties. Results indicate that the minimum success rate of about 68 % can be obtained using the direct use of measurements where as the minimum SR of about 95% can be obtained for the fuzzy system based on the delta measurements for matrix crack prediction.

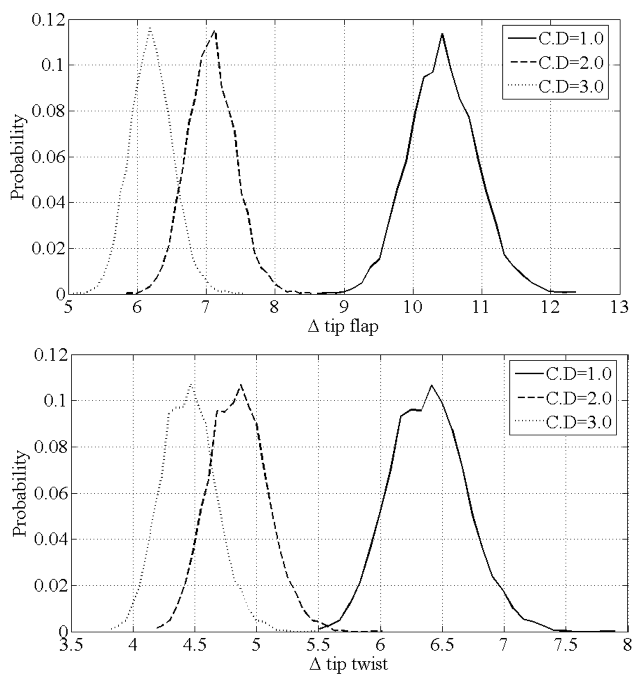

Figure1: Tip deflections for different crack densities

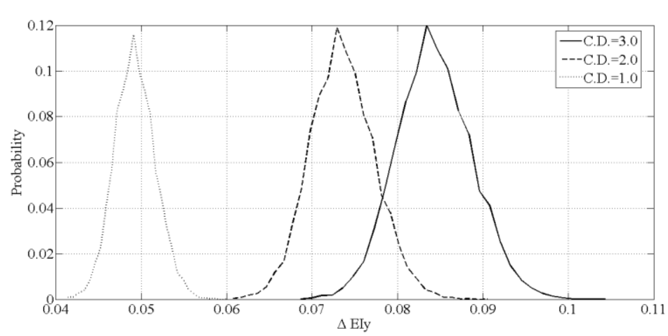

Figure 2: First mode of frequencies

Table 1 SR using direct measurements

Rule	Bending	Torsional	Freq.	SR(%)
1	0.73 (0.025)	0.67 (0.022)	0.94 (0.016)	99.70
2	0.81 (0.028)	0.79 (0.030)	0.89 (0.015)	88.90
3	0.86 (0.030)	0.84 (0.034)	0.87 (0.015)	68.60
4	0.88 (0.032)	0.86 (0.036)	0.86 (0.015)	70.10

Table 2 SR using delta measurements

Rule	Bending	Torsion.	Freq.	SR (%)
1	0 (0.04)	0 (0.04)	0 (0.04)	100.00
2	0.83 (0.04)	0.80 (0.038)	0.46 (0.022)	100.00
3	0.56 (0.028)	0.61 (0.029)	0.70 (0.035)	96.20
4	0.49 (0.025)	0.56 (0.027)	0.80 (0.042)	95.10

References:

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