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Vibration Analysis of Fiber Metal Laminate Beam in ANSYS Parametric Design Language

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Abstract

This paper presents the vibration behavior of F.M.L. (Fiber Metal Laminate). Also presents the behavior of a laminate with and without crack, in a structure, discontinuity introduced for aesthetic point of view or due to design requirements which causes stress concentration and reduction in stiffness. Due to decrease in stiffness the natural frequency of structure is reduced, causes catastrophic failure due to resonance phenomenon. reduction in the value of natural frequency depends up on various factors, associated with crack geometry like crack depth, crack position length of beam fiber orientation angle in composite layer and on metal volume fraction in case of fiber metal laminates. In present study considerable attention is paid on fiber orientation angle, fiber relative crack depth and relative crack position in a cantilever beam of fiber metal laminate.

Keywords: Fiber Metal Laminate, stress concentration, catastrophic failure, crack depth, rack position, fiber orientation angle, cantilever beam.

1. Introduction

Fiber metal laminate is a special class material which is a combination of two technologies first one is metal technology and second one is composite technology. These laminates are formed by metal and composite in which layers of composite layer is sandwich between the two metal layers. Laminate properties depend on the properties of metal and composite. Like the alloys fiber metal laminate deformed plastically, this plastic deformation or degree of plasticity depends on the elastic property of alloy also on the metal volume fraction.

In details, properties of fiber metal laminate depend on various factors like metal volume fraction, fiber volume fraction in composite, stacking sequence of metal – composite layer, orientation of fibers. F.M.L. (fiber metal laminates) are developed specially for aerospace industry due to its wide range of desired properties like low weight density, High strength to weight ratio, High fatigue strength. After the application of GLARE (Glass laminate aluminum reinforced epoxy) in the airbus A-380, fiber metal laminates became popular material for high load applications structure. Fiber metal laminates developed in last 2-3 decades, there are various fiber metal laminates are present like GLARE, (Glass Laminate Aluminum Reinforced Epoxy), CARALL (Carbon Reinforced Aluminum Laminate).

In all structures beams, rods, ties, tie rods, struts and columns are the essential elements, which are used to support different types of loads like beams are used for axial and bending loads, struts for compressive loading. Structures are failed due to the failure of these components, so it become essential to study these components under different failure criterion. In present study vibration attributes are studied with and without transverse crack for transverse vibrations by varying different parameters like angle of fiber orientation, relative crack depth, crack position. By the study of natural frequency behavior and mode shape some authors identified the location of crack, position of crack

Vibration analysis is required for practical application of every structure for its better performance. Also, every system has its own permissible limit of natural frequency. When the permissible limit is reached or crosses by frequency caused due to external force, catastrophic failure occurs. To avoid these conditions it is very essential to know about the natural frequency of any structure which has mass and elasticity properties. Vibrations are generally occur due to unbalance mass in machines and structures.

To prevent failure of any structure which occurs due to undesired vibrations, it is important to determine; Natural frequencies, for avoiding the resonance condition.

2. Techniques Used For Vibration Analysis

To analyze vibration two techniques are available. One is analytical technique and the other is experimental technique. Analytical technique is again divided into two types- one is conventional method (it gives exact solution) and the other is finite element method (it gives approximate solution).
Experimental method has many benefits like it gives high level of control, it provides clear cut conclusions and it provides great coverage to the researcher. In case of same experimental investigation it requires very skilled person, it is very expensive, may have large human errors and also have a restriction due to machine setup to apply boundary conditions.

Analytical technique have some advantages over experimental methods like it is cheaper than experimental methods, it takes less time, no restraint because of machine set up. Generally, all engineering problems are based on real life problems and it is very complex to resolve and found the accurate solution by conventional techniques. Finite element techniques are used to solve these problems. Many finite element solvers are available in market such as ANSYS, FORTRON, ABAQUS etc.

3. Reviews on vibrations of cracked composite beams

Qian et al. developed an elementary stiffness matrix of a composite bar having crack with the help of integrating stress intensity factors and then finite element model fora composite beam having edge crack was established. This developed model was applied for the edge-cracked cantilever beams and then eigen frequencies for various locations and lengths of cracks were obtained. Finally a direct and very simple method useful in detecting crack locations which was supported by the relationship in between Eigenvalue, Eigenvector (eigen couple) and the crack length, was proposed. This method was further purposed for complicated construction with multiple cracks having known stress intensity factors.

Ostachowicz et al. offered a technique to examine the impact of two surface cracks which were open upon the frequencies for the flexural vibrations on a cantilever beam. Here two category of cracks (double sided and single sided) were analyzed. Double-sided cracks occur when there is cyclic loading and occurrence of single-sided cracks is an outcome of fluctuating loading. The assumption of occurrence of cracks in the primary modes of fracture which is also called opening mode was also taken.

Krawczuk et al. represented a model and an algorithm to create the distinguishing matrix by the help of composite bar with transverse fatigue crack. In the developed component, the influences of crack parameters (position and relative depth) and material parameters (relative volume and fiber angle) were examined on changing the first four of the transverse natural frequencies of the composite bar made up of unidirectional composite material.

Hamada et al. calculated the variation in the Eigen-nature of composite beam with crack because of various crack depths and positions. A mathematical and practical observation has been made. The mathematical finite element technique was utilized to figure out the Eigen couples of laminated composite beam through several positions of crack. This model was based on elastic-plastic crack mechanics so as to consider the crack tip plasticity in the study. The model was functioned to find the effects of status of crack, boundary condition and lamina code number on the dynamic attributes of composite beams.

Chondros et al. evaluated vibration theory of a continuously cracked beam for lateral vibrations of Euler Bernoulli beam with crack i. e. single or double edge open cracks. For cracked one dimensional beam Hu-Washizu-Barr formulation was used to obtain the differential equations and the boundary conditions. Displacement field of the cracks was utilized for modification of the stress and displacement fields all over the bar. The crack was modeled as continuously flexible crack with the help of displacement field in the locality of the cracks which was found by techniques of fracture mechanics.

Liew et al. demonstrated the major attempt of using the wavelet theory in detection of the crack in any structure. As a contextual observation, detection was done using the wavelet theory for a structural beam having simply supported configuration and a transverse edge non- propagating open crack. A numerically simulated model of the cracked bar was inferred and the wavelet terms in the space domain were anticipated for solution. For correlation requirement, the beam with simply supported configurations having crack was comprehended using both of the Eigen theory and the wavelet theory for examination. The results verified that the detection of cracks by means of wavelet theory was efffective while it can hardly be acknowledged by the conventional eigenvalue examination.

Murphy et al. analyzed the feedback of vibration and stabilizing character of a beam in which crack was occuring throughout the beam length in between two fixed supports. Some relations were formulated by the help of fracture mechanics and Hamiltoinciple. For whole observation, it was supposed that the crack was open and shallow, means situation of impact was not applicable here. Study of Eigen couple described the nature of vibrational and stability attributes. As the crack propagated throughout the beam, fluctuations in natural frequencies and stability were recorded.

Zak et al. formulated the work models of a finite element delaminated beam and delaminated plate component. A broad practical investigation was conceded out to record variations in the 1st three bending natural frequencies because of delamination. The outcomes of the mathematical calculations were almost same as the outcomes of the experimental observations.
Wang et al. examined the vibrations of a circular shaped plate

surface reinforced by two piezoelectric layers, considering the Kirchhoff plate model. The nature of the electric potential field in the piezoelectric layer was expected to be like that of the Maxwell electricity produced via friction condition. The theoretical model was approved by contrasting the frequencies of resonance of the piezoelectric coupled round plate acquired by the hypothetical model and those acquired by limited component examination. The mode shapes of the electrical potential acquired from free vibration examination was appeared to be non-uniform for most of the part. The piezoelectric layer was appeared to affect the frequencies of the structure. The proposed display for the examination of a coupled piezoelectric plate gave a way to acquire the conveyance of electric potential in the piezoelectric layer. The model gave a plan reference for applying piezoelectric material, for example, an ultrasonic engine.

4. Material and Methods

4.1. Governing Equation

For free vibration condition Governing equation which governs of the beam is given by

$$[K]-\omega^2[M]\{q\} = 0$$

In above expression,

K= Stiffness Matrix
q = Degree of Freedom
M= Mass Matrix

4.2. Model of Beam

In the present paper for the purpose of investigation a prismatic cantilever composite beam of rectangular cross-section is used which have a transverse crack at a distance L_1 from the fixed end, and a depth of crack ‘a’. In the present model of beam crack is transverse crack having V-shape. Length, height and width of the beam are L, H and B respectively as shown in fig. 4.1. All the fibers are assumed to be oriented at an angle α.

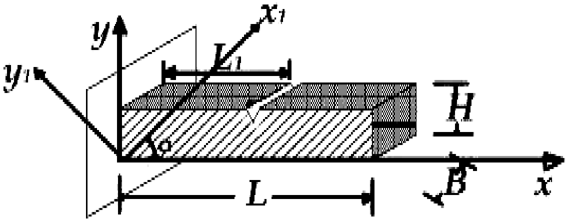

Fig. 4.1 Labelled layout of composite beam with transverse crack in clamped-free configuration.

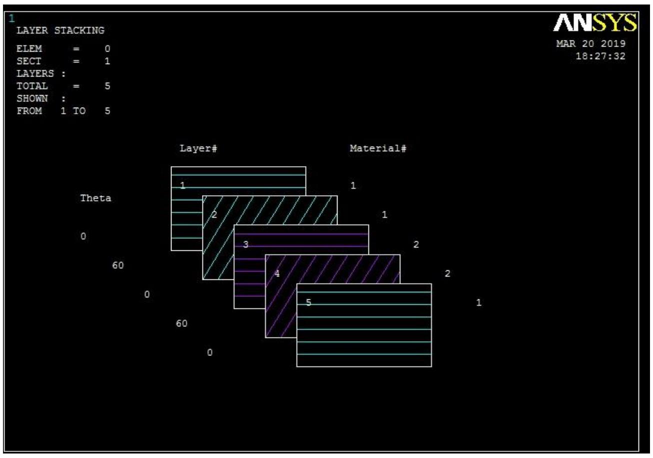

Fig. 4.2 Sequence of layers of composite and metal in Fiber Metal laminate

4.3. Description of used elements for meshing

Solid shell type of element is used in the present analysis which shows two merge properties of shell element and solid element. **Solid shell 190 (SOLSH 190)** element is used in the present analysis.

In the present analysis beam of laminated composite material is used and the element type used is Solid shell which is used for layered type of material. The laminated composite materials are in the form of no. of layers of composite material called lamina. Solid shell type element is used for large range of thickness means we can used SOLSH 190 element type for thin to moderate thickness structure. In terms of accuracy of results SOLSH 190 is suitable for both 2D and 3D type of problem but SHELL type of element provide better results in 2D problems only.

SOLSH 190 element has 8 nodes and each node have three degrees of freedom that are translational motions in x, y & z directions.

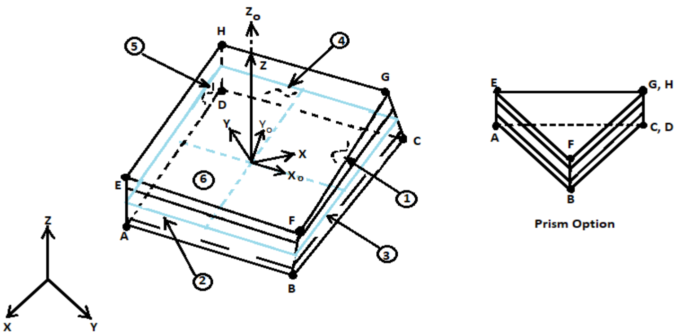

Fig. 4.3. Geometry of SOLSH 190 element

For present analysis GLARE is taken, in which Aluminum alloy Al 2024 - T3 and S-glass epoxy is present, for metal volume fraction .6 and for S- glass epoxy fiber volume fraction .5. For present study, beam of 5-layer hybrid laminate is modelled in ANSYS APDL with the length, width and thickness of 1000 mm, .50 mm, and thickness 25 mm respectively.

Table 4.1. Material properties of Al 2024- T3

Material properties of Al 2024- T3		
Density (kg/m^3)	Young's Modulus (GPa)	poission's ratio
2780	73.1	0.33

Table 4.2. Properties of s- glass Epoxy

Young's Modulus (GPa)	Em	3.25
	Ef	86.9
Modulus of Rigidity (GPa)	Gm	1.25
	Gf	35.61
Poisson's Ratio	νm	0.3
	νf	0.22
Mass Density (kg/m^3)	ρm	1250
	ρf	2490

5. Results and Discussions

Effects of various factors like, Fiber Volume Ratio (V) and influence of Ply Orientation Angle on first three lowest Nat. Freq. are investigated

5.1. Effect of Orientation Angle For Intact Beam

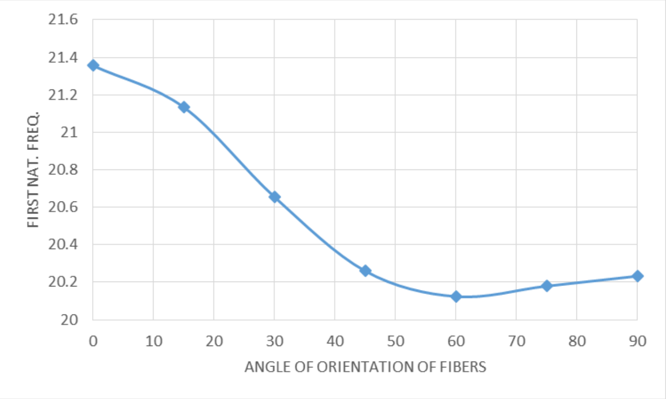

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Fig. 5.1. Effect of angle of orientation of fibers on First Nat. Freq. (Hz).

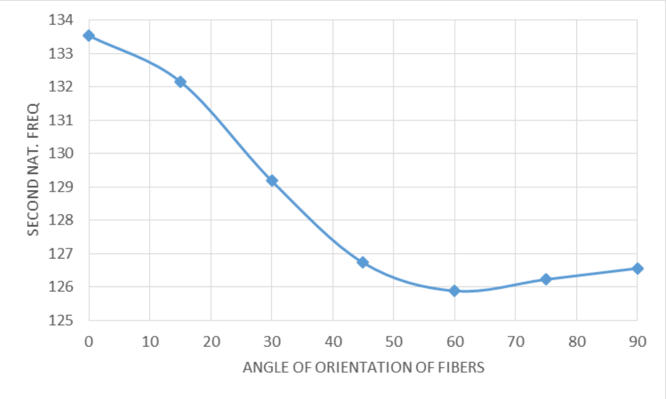

Fig. 5.2. Effect of angle of orientation of fibers on Second Nat. Freq. (Hz).

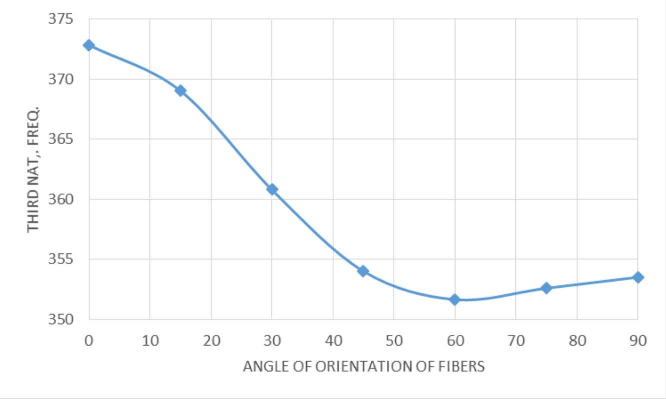

Fig. 5.3. Effect of angle of orientation of fibers on Third Nat. Freq. (Hz).

5.2. Effect of Relative Crack Depth for crack position (L1/L) = 0.1 for the 60 °angle of orientation of fibers

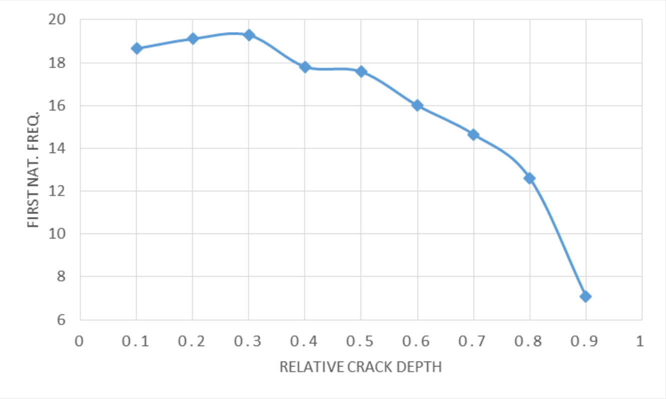

Fig. 5.4. Effect of relative crack depth on First Nat. Freq. (Hz).

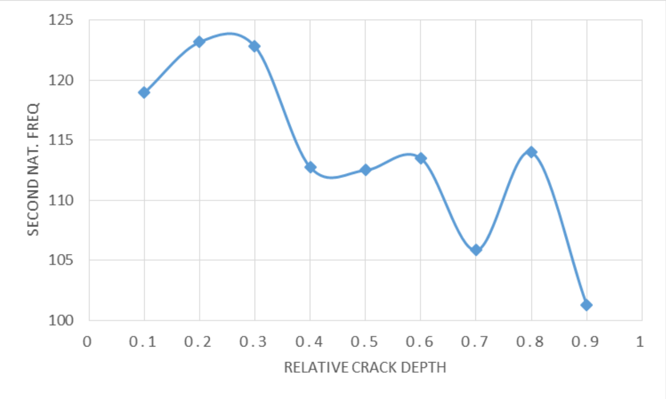

Fig. 5.5. Effect of relative crack depth on Second Nat. Freq. (Hz).

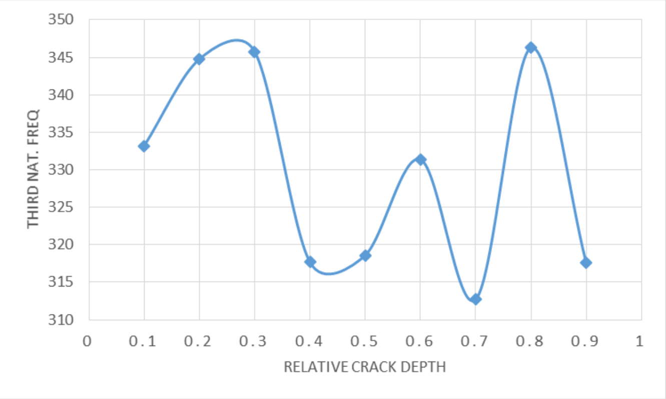

Fig. 5.6. Effect of relative crack depth on Third Nat. Freq. (Hz).

5.3. Effect of crack position for Relative crack depth 0.8 for the 60 ° angle of orientation of fibers in both layer of composite (M/θ/M/θ/M)

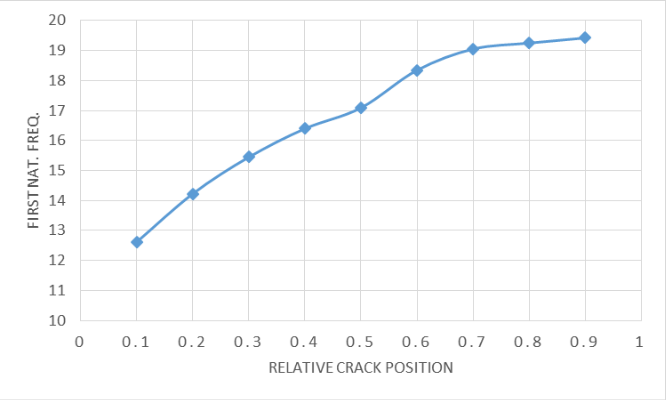

Fig. 5.7. Effect of crack position on First Nat. Freq. (Hz).

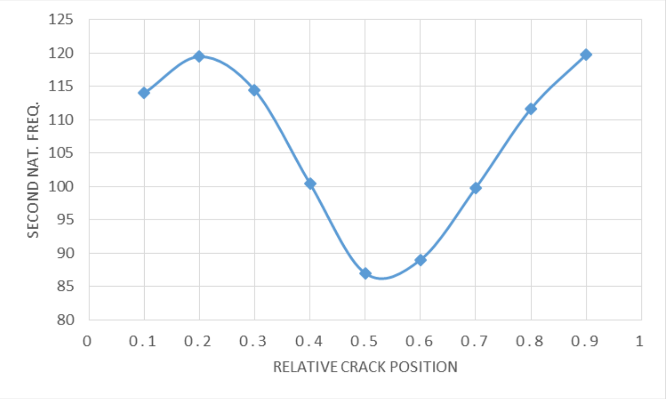

Fig. 5.8. Effect of crack position on Second Nat. Freq. (Hz).

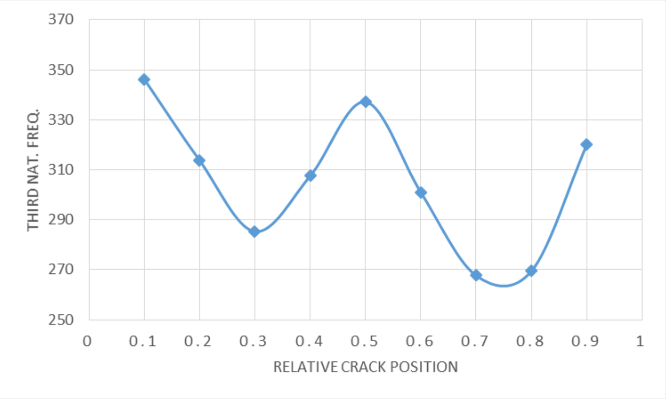

Fig. 5.9. Effect of crack position on Third Nat. Freq. (Hz).

4. SUMMARY AND CONCLUSION

1. It is clear from present analysis that for 5 layered (M/θ/M/θ/M) fiber metal laminate first three natural frequencies for transverse vibration in intact beam is minimum at 60° and further start increasing as the angle of orientation of fibers increase in beam without crack.
2. For a cracked beam, it is found in present analysis that all first three natural frequencies for transverse vibration is maximum in between .2 to .3 for relative crack depth with crack position .1 for (M/60/M/60/M) configuration of fiber metal laminate.
3. For relative crack depth 0.8, it is observed that for fixed-free configuration of beam for (M/60/M/60/M) first transverse natural frequency increases as crack position increases.
4. For relative crack depth 0.8, it is observed that for fixed-free configuration of beam for (M/60/M/60/M) second transverse natural frequency is maximum at .9 and lower in between 0.5 to 0.6 crack position.
5. For relative crack depth 0.8, it is observed that for fixed-free configuration of beam for (M/60/M/60/M) third transverse natural frequency is maximum at .5 and lower in between 0.7 to 0.8 crack position.

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