ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

TITLE –THE PRINCIPLES OF COIN-TAP METHOD OF NON-DESTRUCTIVE TESTING

Sung Joon Kim*, Dong-Chul Chae

Korea Aerospace Research Institute, 45 Eoeun-Dong, Youseong-Gu, Daejeon, 305-333, Korea

Phone : 82-42-860-2301 FAX : 82-42-8602-2009
yaelin@kari.re.kr

Abstract The "coin-tap" test has the ability to indicate damage in a structural element due to a localized change of stiffness. The change in vibration signature may be detected by ear or more precisely by measurement of the dynamic contact force [1]. In this paper, a coin-tap test method for discriminating between measurements made on sound and delaminated structures is present. It has been shown that the characteristics of radiated sound from a structure during a tap are changed by the presence of defect beneath the surface of the structure. For structurally radiated noise, the sound field is directly coupled to the structural motion. Therefore, Impact response analysis should be computed. In this study, the radiated sound induced by impact is obtained by solving the Rayleigh integral equation. And the 2-D equivalent delamination model is used to analyze the impact response and acoustic analysis. Predicted impact responses using 2-D equivalent delamination model are compared with the numerical ones from the 3-D non-linear finite element model. From the results, it is shown that the 2-D simplified model was found to be reliable for predicting the impact force histories and sound pressure.

INTRODUCTION

The use of laminated composite structures has many potential applications in a variety of engineering fields. However, they are mostly used in a laminated form with relatively weak interlaminar interfaces which are vulnerable to transverse loads such as impacts arising from a falling mass. The presence of delaminations can cause significant degradation of the structural response characteristics. The coin-tap test is one of the oldest methods of non-destructive testing and it is regularly used for testing laminated structures. The test requires an operator to tap each point of the structure to be inspected with a coin, and listen to the resulting sound radiated by structure. When a structure is struck with a hammer, the characteristics of the impact are dependent on the local impedance of the structure and on the hammer used. Damage such as an adhesive disband and fatigue damage results in a decrease in structural stiffness, and hence a change in the nature of impact [2]. Adams showed that it is possible to produce a version of the coin-tap test which depends on the measurement of the force input to the test structure during the tap [3]. In this paper, a sound based non-destructive method is proposed. This method is using the difference between radiated sound of healthy structure and delaminated structure. For structurally radiated noise, the sound field is directly coupled to the structural motion. Therefore, impact response should be analyzed. Generally, the finite element method on the impact response of the laminate has been known to require long computation time. Shivakumar et al. did not use the finite element method to analyze the impact response of the laminate but used the spring-mass model to efficiently predict the impact force history [4]. In their study, the contact energy due to local indentation as well as transverse shear energy and bending energy of plate are considered, and they reported that the contact energy can be neglected in the impact by relatively low velocity foreign object on a flexible or thin plate. Choi proposed the spring element model using linearized contact law. In their study, they have shown that the linearized contact law approach could be applied to low-velocity impact response analysis problem with using general purpose FEM software [5]. To investigate the impact response on delaminated laminates, 3-D finite element model is used using gap element to avoid the overlap and penetration between the upper and lower sub-laminates at delamination region. But the use of three-dimensional elements to predict the impact response of delaminated composite structures is inconvenient because of a quite number of elements necessary to obtain numerical solutions.

Impact response analysis using general-purpose FEM software

Figure 1 shows FEM model for impact response analysis using 1-D spring element supported in general –purpose FEM software. The mass of impactor is lumped at the end of the spring mass, and the other end of spring element is attached to laminate at impacted location. After FEM analysis we can extract the compressive force history acting at the spring. In present study, MSC/NASTRAN was used as general-purpose FEM software. In FEM modeling 3-node plate element was used and transient dynamic analysis was performed with the initial condition, which is that initial speed of the lumped mass was loaded as impact velocity.

Delamination Model

To prevent the overlap and penetration, 3-D non-linear finite element analysis was performed using MSC/NASTRAN to determine the impact response of graphite/epoxy composite specimens.

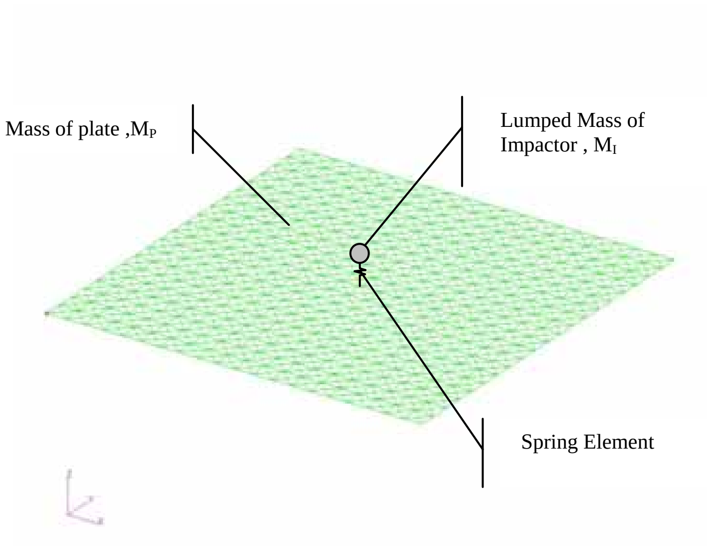

Figure 1 Spring element model using general-purpose FEM software

Eight-node solid elements and gap elements were used to model delamination. The gap elements are inserted along the delamination interface surfaces for preventing penetration of the upper and lower sub-laminates during impact analysis process. In this study, 2-D simplified delamination model was used for comparison with 3-D non-linear finite element model. Figure 2 shows the schematic of the delamination modeling. The delaminated area elements are copied, and each half laminate was assigned the appropriate properties: laminate A: $[0]_8$, thickness = 1.0 mm; laminate B: $[0]_4$, thickness = 0.5 mm; laminate C: $[0]_4$, thickness = 0.5 mm. Finally the outlining nodes of both groups were tied together by constraining all of their degree of freedom. Seth has proposed the simplified delamination model and has shown that the frequency response results are very agreed with tests [6].

Delamination model verification

Delaminations were located at the midplane of the plates. The analysis model of the laminate is 15 x 15 x 0.1 cm, and the boundary condition of the plate has four edges clamped. The delaminated area of case1 is 1.5 x 1.5 cm, and case2 is 4.5 x 4.5cm. And the material properties are shown in table 1. A comparison of impact force histories between 3-D non-linear model and 2-D simplified model is shown in Figure 3. As shown from the figures, the numerical results obtained by simplified model provided appropriate result. A comparison of impact force histories with and without delaminated is shown in Figure 4 when the mass ratio (mass of impactor/mass of plate) is 35.0 and impact velocity is 5 m/sec.

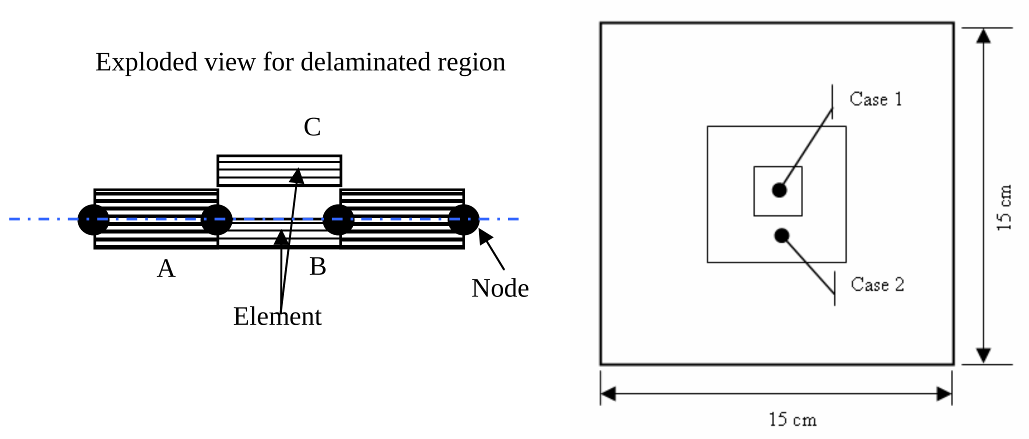

Figure 2 Schematic of delamination modeling and configuration of delaminated area

Table 1 Material properties [5]

Material properties of lamina	E_1 = 120 GPa, E_2= 7.9 Gpa G_{12}=G_{13}=G_{23}= 5.5 Gpa ν_{12} = 0.3 ρ =1582 kg/m^3 Thickness = 0.125 mm
Material properties of impactor	E = 207 Gpa ν =0.3

Impact force histories are decreased by the presence of delamination. This result would be expected because plates with delaminations should be less stiffness than undamaged plates. The larger delaminations produced the greatest decrease in impact force histories and increase in contact time duration. The difference in sound produced by the two taps may be explained by studying the frequency content of the two force pulses. This is achieved by carrying out a Fourier transform of the force-time records to produce the power spectrum density spectra shown in Figure 5. The amplitude of power spectrum density input to the delaminated structure falls off rapidly with increasing frequency, while the impact on the sound structure has a much lower rate of decrease of PSD with frequency. This means that the impact on delaminated area will not excite the higher structural modes as strongly as the impact on the sound zone. Therefore the sound produced does not contain the higher frequencies and the structure sounds duller.

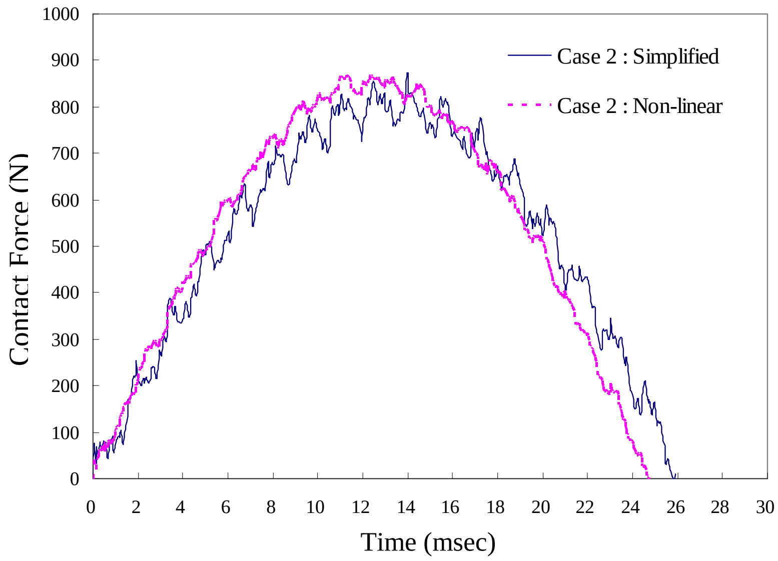

Figure 3 Impact force histories analyzed using the simplified model and the 3-D non-linear model

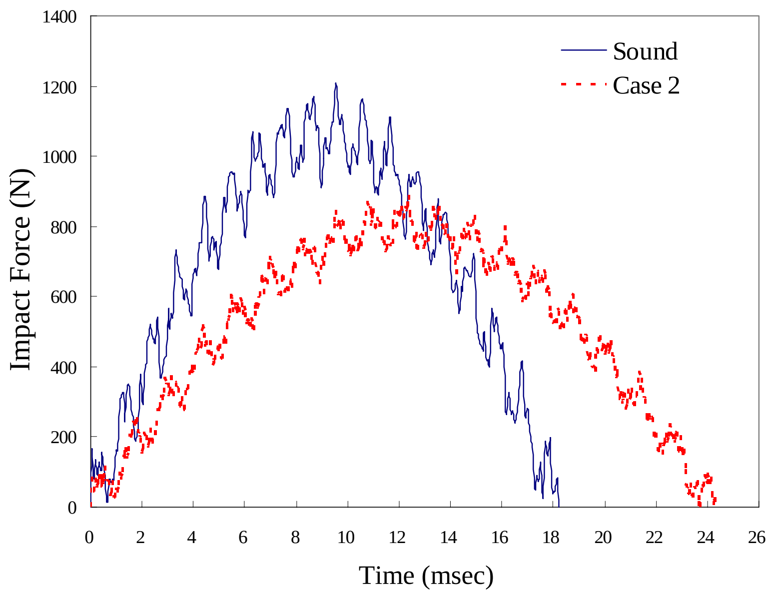

Figure 4 Impact force histories for case2

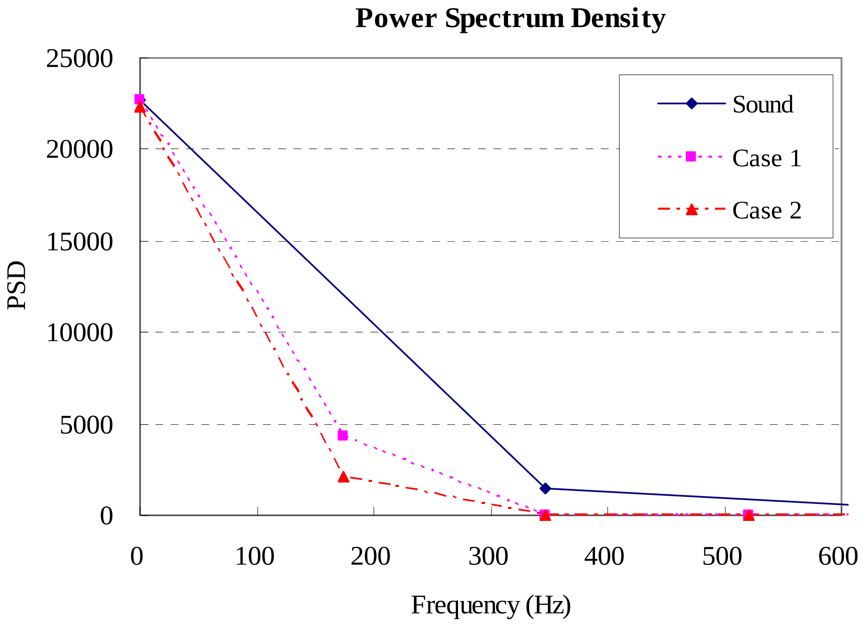

Figure 5 PSD spectra of time histories shown in Figure 4

Calculation of acoustic pressure

The acoustic pressure radiated from a vibration plate can be obtained by evaluating the Rayleigh surface integral where each elemental area on the plate surface is regarded as a simple point source of an outgoing wave and its contribution is added with an appropriate time delay. The acoustic pressure *p(r,t)* at the observation point *P* with Cartesian coordinate(x_0,y_0,z_0) at time t caused by the vibration of the plate is calculated by using the Rayleigh integral.

$$p(r,t) = -\frac{\rho_a}{2\pi}\int_{(S)}\frac{1}{|r-r_0|}\frac{\partial^2}{\partial t^2}W(r_0, t-\frac{|r-r_0|}{c_a})dS \qquad (1)$$

Where ρ_a and c_a are, respectively, the mass density and wave velocity of the acoustic medium, $\frac{\partial^2 w}{\partial t^2}$ is the acceleration time history of the plate obtained from impact response analysis, *R* is the distance between the observation point P and infinitesimal element at (*x*,*y*) on the plate surface. The properties of air as the acoustic medium are density ρ_a =1.21 kg/m^3 and speed of sound c_a =340m/s.

Computational Results

To investigate the effect of delamination on radiated sound, a sample case was analyzed when the mass ratio (M_I/M_P) is 1.92 and impact velocity is 0.5 m/sec. The difference in the acoustic sound pressure produced by impact is shown in Figure 6. The sound pressure is calculated at the observation point. The observation point is 15 cm above the center of the plate. Figure 7 shows that the larger delaminations produced the decrease in the center frequency of sound pressure.

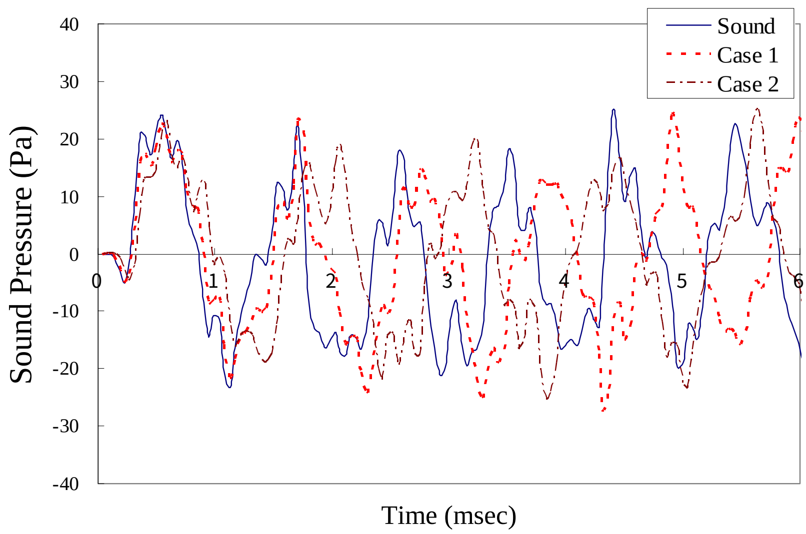

Figure 6 Sound Pressure Histories

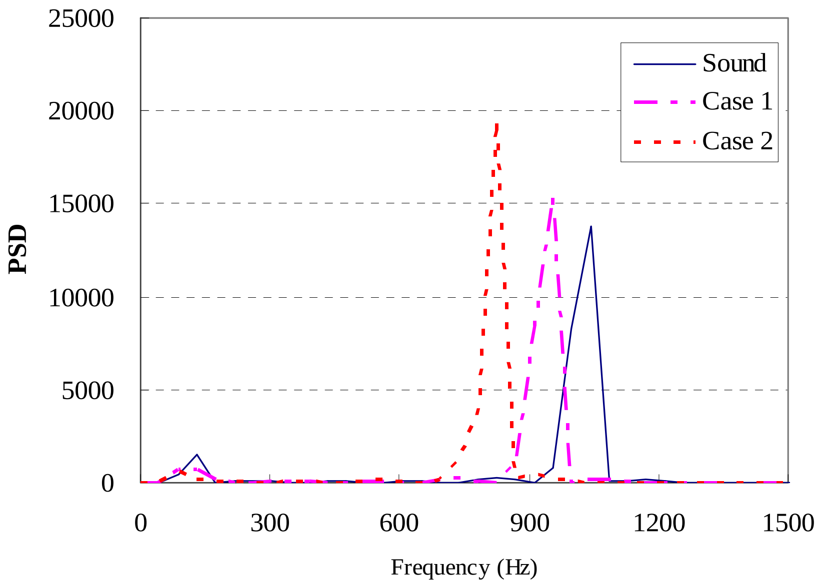

Figure 7 PSD spectra of time histories shown in Figure 6

CONCLUSION

The physical basis of the coin-tap test has been demonstrated, the change in the sound produced when a delaminated area is tapped being due to a change in the force transmitted to the structure by the tap. It has been shown that this process may be modeled by representing the delamination as a 2-D simplified delamination. In this paper, comparisons between 3-D non-linear delamination model and 2-D simplified model have performed to investigate the impact response behavior. From the results, the 2-D simplified model was found to be reliable for predicting the impact force histories and sound pressure. The chief advantage of the coin-tap method over higher ultrasonic testing is that no couplant is needed between the structure and tapping head. The technique is therefore particularly attractive for use in the field. There are two kinds of coin-tap test method. One is based on the impact force histories that produced when the structure is struck. And the other is based on sound pressure histories. The first one requires the time histories of the force input to the test structure to be captured, and this can be done via transducer in tapping head so no transducer need be attached to the structure. The second requires the time histories of the sound that radiated from the structure. The sound based coin-tap test requires the Fourier transform of the sound pressure histories to be computed and compared with a standard from a sound structure. It is shown that the two kinds of coin-tap test are useful and practical diagnostic tool for detecting localized delamination in composite laminates

REFERENCES

[1] Williams, S. M., and Smith, J. W., “An intelligent tap test as an inspection tool for corrosion in chequer plate floors,” *Journal of Sound and Vibration*, Vol. 257, pp. 857-867 (2002).

[2] Cawley, P. and Adams, R. D., “ The mechanics of the coin-tap method of non-destructive testing,” *Journal of Sound and Vibration*, Vol. 122, pp. 299-316 (1988).

[3] Adams, R. D. and Cawley, P., 1985 in *Research Techniques in Non-destructive Testing* (R. S. Sharp, editor) 303-360. Vibration techniques in non-destructive testing.

[4] Shivakumar, K. N., and Elber, W., “Prediction of impact force and duration due to low-Velocity impact on circular composite laminates,” ASME *Journal of Applied Mechanics*, Vol. 52, Sept., pp. 674-680 (1985).

[5] Choi, I. H., and Lim, C. H., “Low-velocity impact analysis of composite laminates using linearized contact law,” C*omposite Structures*, Vol. 66, pp. 125-132 (2004).

[6] Kesseler, S.S et al., “Damage detection in composite materials using frequency response methods,” Composites, Part B Vol.33, pp. 87-95 (2002).