MODAL ACOUSTIC EMISSION BASED LOCATION METHOD IN HONEYCOMB CORE SANDWICH STRUCTURE

Y. Liu, B.J. Pang, B. Jia, Z.Z. Chang

Hypervelocity Impact Research Center, P O Box 3020, Science Park, Harbin Institute of Technology, ZIP: 150080, China, Email: Pangbj@hit.edu.cn

ABSTRACT

We report on the acoustic emission signal propagation and modal acoustic emission (MAE) source location in aluminum honeycomb core sandwich structures. An experiment study supported by modal acoustic emission method is presented that symmetric and anti-symmetric mode of wave can be detected, location method based on virtual wave front is used to locate the acoustic emission source. A linear array of sensors receive signals from lead break and low velocity impact AE source, frequency response of sensed signal and wave velocity in different directions are obtained experimentally. The attenuation nature of different wave mode in the sandwich panel is monitored by measuring the signal amplitude at different distance measured from the AE source. Reduce the noise influence from acoustic emission signal by low-pass-filtering, anti-symmetric wave is selected in the lead beak and low velocity case, self-adaptive threshold value method is used to ensure the arrival time, the impact location is derived by a modified virtual wave front algorithm.

1 INTRODUCTION

Honeycomb core sandwich panels with metal and composite face sheets are widely used in aerospace structures for their specific stiffness and strength. As the increase of human space activities, the increasing seriousness of space debris environment has deteriorated, the threat to on-orbit spacecraft is severe. In order to real-time monitoring the space debris hypervelocity impacts, an onboard acoustic emission system is presented to locate the impact position [1].

Acoustic emission technology is designed for monitoring acoustic emission produced within failure or stress appear in material, AE waves are collected after they have traveled through the material, AE source location has aroused wide concern, consequently varieties of location method has been studied[2-4]. Modal acoustic emission is a technology to establish relationship between AE wave and specific physical process by using Lamb wave theory [5], it's applied a convenient method to the analysis and understanding the AE wave in composite laminates. In order to solve the isotropic material location problem, researchers measure the wave velocity of certain frequency and wave mode with time-of-flight method, then the algorithm of AE source location can be obtained. Salihe use nonlinear equations with transducers arranged in a triangulation position, established a location algorithm of AE method [6]. The solution of the angles use a wavelet tool would be obtained by solving the equations, AE source can also be located [7]. Linear array for detection and location the damage, low frequencies first anti-symmetric mode of Lamb wave propagation are simulated [8].

AE wave in honeycomb core can be regarded as a laminate problem, the way solve laminates also can be referenced. In HC plate there also exist varieties of wave modes of Lamb wave, each mode of Lamb wave have its attenuation and dispersion law. To locate the AE source on HC core sandwich, lead break and low velocity impact AE source has been utilized to select the proper mode of wave, virtual wave front algorithm is been conducted.

2 EXPERIMENT

In the present work an aluminum honeycomb core metal face sheet sandwich panel is used. The experimental AE source include lead break and glass projectile impact respectively, the testing panel has a dimension of 1500mm×1500mm×21.6mm thickness. The face sheets are 0.8mm thick aluminum sheets boned with 20mm thick aluminum honeycomb core. This shape of honeycomb core sandwich behaves low dynamic stiffness on the wave propagation in this panel. Time and frequency response of AE signal is related to the thicker skin to core ratio and the applied loading. The damage made by impact loading on the interface type on the honeycomb core sandwich can be divided into 4 cases, minor or major dimensions cratering for HC front facesheet, impact hole on the front facesheet with bullet stock in the honeycomb, minor or major dimensions hole for HC rear facesheet and impact hole on the rear facesheet. Guided wave in honeycomb core sandwich has the different feature, in order to study the propagation characteristics of AE signal in honeycomb core sandwich, the dispersion and attenuation of Lamb wave has to be taken into account. Elastic aluminum layers play a major role in propagation characteristics, viscoelastic effect due to the adhesive layer and inhomogeneous dynamic strain at the HC core interface should be simplified in the theoretical study, S0 and A0 mode of Lamb waves are expected with their perturbation in dispersion characteristics.

Proc. '6th European Conference on Space Debris'
Darmstadt, Germany, 22–25 April 2013 (ESA SP-723, August 2013)

In our research, the honeycomb core sandwich is considered as an anisotropic material, the wave velocity of S0 and A0 mode is a function of the propagation direction and frequency [9]. Due to the multiple structure and production process, the dispersion characteristics of HC core sandwich is different from theoretical analysis, wave velocity of each mode should be calibrated in advance. Lead break and air gun impact tests are conducted, 6 broadband ultrasonic sensors array is settled in 12 directions from 0 degree to 165 degree in step of 15 degree, as is shown in Figure 1, excitation source stand in the centre of circle. The panel was kept hanging to avoid touching on the floor. In lead break experiment, a pre-amplifier is used to amplify the AE signal with the amplification factor 40dB or 60dB, the first sensor keeps 150mm distance from source, such that S0 mode and A0 mode Lamb wave could be obviously observed and distinguished in time domain. In air gun impact case, glass bullets with diameter 5.980mm and quality 0.2798g are launched to impact the panel, average impact velocity is 91.78m/s.

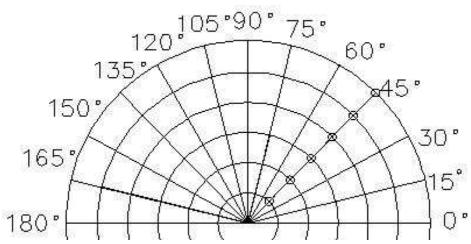


Figure 1 experimental setup of the measurement of the wave velocity

3 ANALYSIS OF EXPERIMENTAL RESULTS

Lead break and air gun impact experiment in every direction conducted 5 times, excitations are repetitive loading in the same point so that all the AE signals arrive to sensors at the same time and have similar wave form, averaging the repeating experiment results, SNR of the AE signals can be significantly increased. Facesheet of the panel have perforation damage after impact as is shown in fig.2, when facesheet break, amplitude of symmetric mode (S0) is obviously larger than the opposite case, S0 mode of AE signal is mainly generated in the in-plate load.

Fig. 3 shows the lead break signals obtained by the six receivers, S0 and A0 mode can be obviously observed, the group velocity of S0 mode is higher than that of S0 mode, wave packets corresponding to S0 mode propagate faster, this is similar to the law of aluminum plate but velocities are lower than that in plate with facesheet shape because of adhesive and inhomogeneous dynamic strain influence. Amplitude of S0 mode decay fast, even lower than the noise level when 300mm away from the AE source, by contrast, that of A0 mode decays more gently. Typically amplitude of A0 mode packet is greater than S0 case, for anti-symmetric wave mode creates bending throughout the entire cross-section of panel.

Figure 2 impact location on the facesheet

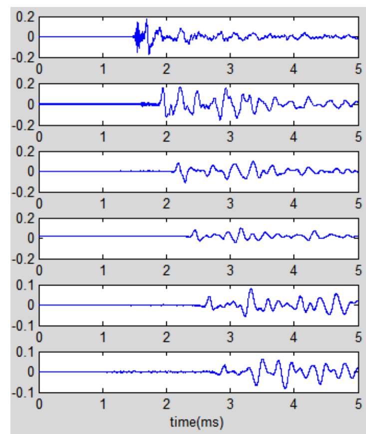


Figure 2 AE signals inspired by lead break

Fig. 4 shows air gun impact AE signal of six transducers, in this case S0 mode is much less than A0 mode because of lack of inner loading in the facesheet. Amplitude of impact signal is much larger than lead break signal. Because of S0 mode on the panel attenuated quickly, only A0 mode wave is taken into account.

Figure 5 shows the wavelet spectrum of AE signal on honeycomb core sandwich, two center frequencies of overall AE signal in (a) represent that of S0 and A0 mode, red curve is wavelet coefficient when peak amplitude of A0 mode arrival, the arrival time of A0 mode can be record. A0 mode of lead break AE signal keeps in 50 kHz, S0 mode in about 140 kHz and decay fast when path from AE source to receiver getting longer. Frequency of wavelet coefficient of air gun impact AE signal also centre in 50 kHz, equivalent to the A0 mode from lead break excitation source, wave velocity is also at approximately the same value, this is accord with dispersion characteristics. A0 mode is the only mode in air gun impact AE signal. When acoustic event appears in honeycomb core sandwich, a low-pass-filter in lower 100kHz can be introduced for getting A0 mode of wave, because S0 mode exist in the signal may trigger the sensing system which affect the arrival time getting in the location method.

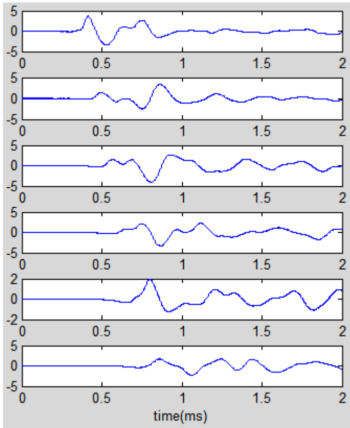
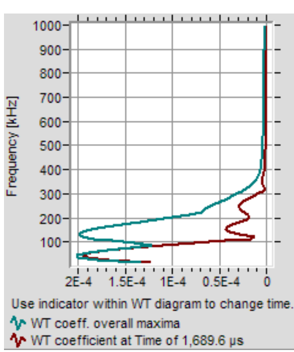


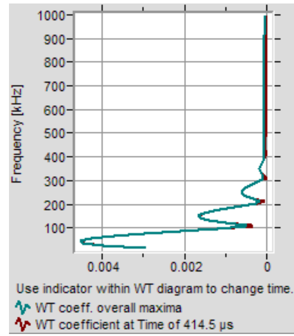
Figure 4 AE signals inspired by air gun impact

The behavior of the AE signal frequency remains in the range about 50 kHz when propagation directions vary, excitation source of each experiment is repeatability. By measuring peak amplitude of A0 mode of each channels, that of signal obtained by receivers in line plot against directions as shown in Fig. 6, nature of decay in signal amplitude as an exponential function of direction and distance as Eq.1, that can be written as (1). Fig. 7 shows attenuation coefficient α in a variety of direction, which vibrate around 0.0912. Location method has to ensure the amplitude of specific mode of AE signal is higher than noise level after propagating on board, attenuation function affect the transmission capacity of AE wave, which means this method has a effectively range of transducers placement. In low velocity loading case, a A0 mode wave is used for locate AE source, yet in hypervelocity case, S0 mode will have a large initial amplitude, S0 mode maybe used in location problem for its much faster velocity which will improve the positioning accuracy.

$$y = Ae^{-\alpha x} \quad (1)$$



(a) lead break



(b) air gun impact

Figure 5 wavelet coefficient of overall signal and A0 mode arrival time

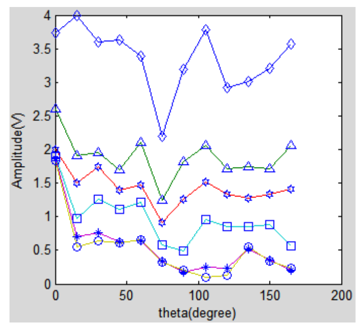


Figure 6 peak amplitude of linear sensors array in different directions

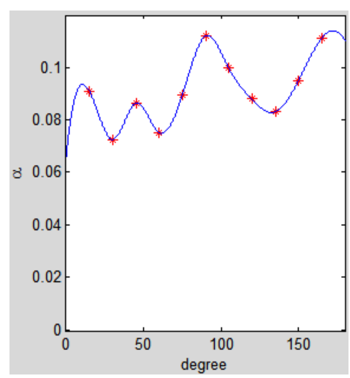


Figure 7 α of A0 mode attenuation function

Group velocities of A0 mode in each direction is calculated by fitting the distance and arrival time with least square method and averaging with repeated impact test of lead break and air gun impacts, cubic spline interpolation method is proposed to fitting the experimental velocities, that in all directions is shown in Fig. 8.

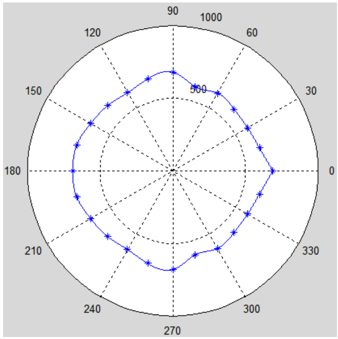


Figure 8 group velocities in 50 kHz of A0 mode in all directions

4 LOCATION METHOD

In order to locate the AE source, accurate arrival time is a significant parameter in calculation. A 100 kHz low-pass-filter is used in location method with A0 mode of wave. A self-adaptive threshold value method can also reduce the error of arrival time obtaining. Collect the noise signal before starting of data acquisition, averaging the noise level and multiple by a gain value that effective in specific, when the signal firstly over this value can be recognized as A0 mode arrived.

With the A0 mode velocities in all directions are obtained, a virtual wave front method is used for AE source location. Several receivers are placed on the facesheet, coordinates are record as (x_i,y_i)(i=1:N), initial time of impact ist_0, calculation value is t_0', virtual wave front could be written as Eq. 2

$$l_i'(\theta) = (t_0 + t_i) \times v(\theta) \quad (2)$$

Therefore calculation value of impact location can be estimated as Eqs.3-4

$$x_0' = x_i + l_i'(\theta) + cos(\theta) \quad (3)$$

$$y_0' = y_i + l_i'(\theta) + sin(\theta) \quad (4)$$

If calculated initial time $t_0' = t_0$, virtual wave fronts of multiple channels can converge to one point, on the opposite a point of intersection will obtained by arbitrary two neighboring channels, there will be C_N^2 intersections, record as (x_{ij}, y_{ij})(i, j ∈ 1 ⋯ N), with the average value (x'', y''). Each of the intersections corr-esponding to a travel time t_i, as the t_0' coming closer to t_0, all intersections will approaching to the point that AE excitation appears. Calculate the standard deviation of distance, t_0' can be obtained when the standard deviation reach the least value then we have the AE source location. In this method t_0 must have a calc-ulating range, that satisfy the possible extremum of travelling time. A one-dimensional function of time will be solved for obtain the real time of AE events.

5 CONCLUSION

In order to research the location method on the honeycomb core sandwich for the development of on board sense system, the propagation characteristics are studied by lead break and low velocity impact experiment. Symmetric mode and anti-symmetric mode wave are extensively existing in the AE wave, appropriate mode should be determined for the location method. In order to decide the mode for location, the attenuation function is obtained by lead break and air gun impact experiment, and in this case A0 mode of AE wave on HC core sandwich is selected. In case of dispersion of laminates, a central frequency is detected for getting the arrival time. Wave velocities for location of all directions are calculated by varieties of experimental results. A low-pass-filtering is used for reduce the influence of noise and other mode of wave, arrival time can be gain by self-adaptive threshold value method, the virtual wave front algorithm is employ for AE source location.

6 REFERENCE

[1] Gorman Michael R., “Plate Wave Acoustic Emission,” J. Acoustical Society of America Vol. 90 No.1, July 1991

[2] IADC WG3 members. (2008). Sensor Systems to Detect Impacts on Spacecraft Version: 1.0.

[3] Liu, H.X., Zhang, H. & Ma, R.X. (2003). Nondestructive Testing Techniques for Composite Materials. Nondestructive Testing. 25(12), 631-634

[4] Sun, L.Y., Li, Y.B. & Qu Z.G. (2008). Study on Acoustic Emission Pipeline Leakage Detection Based on EMD Signal Analysis Method. Piezoelectrics & Acoustooptics. 30(2), 239-241

[5] Z.D. Liu, B.J. Pang, Q. Tang (2009). A method Based on Virtual Wave Front For Acoustic Emission Source Location In Laminates. 5th European Conference on Space Debris[C]. SP-672, July 2009

[6] Yamada, Y., Mizutani, Y. (2000). Lamb Wave Source Location of Impact on Anisotropic Plates. Journal of Acoustic Emission. 18, 51-60

[7] Jeong, H.J.& Jang, H.S. (2000). Wavelet Analysis of Plate Wave Propagation in Composite

[8] Diaz Valdes SH. Structural Integrity Monitoring of CFRP Laminates Using Piezoelectric Devices. PhD thesis. London, UK: Department of Aeronautics, Imperial College; 2000

[9] Rhee, S.H., Lee, J.K.& Lee, J.J. (2007). The Group Velocity Variation of Lamb Wave in Fiber Reinforced Composite Plate. Ultrasonics. 47, 55-63