ACOUSTIC EMISSION DETECTION AND LOCATION FOR HYPERVELOCITY IMPACTS

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ABSTRACT

Acoustic emission (AE) analysis is used for characterization and to location for hypervelocity Impacts. Two different Acoustic Emission (AE) sensors were used to detect the arrival time and signals of the hits. Hypervelocity Impacts were generated with a two-stage light-gas gun firing small Aluminum ball projectiles (4mm, 6.4mm). In the impact studies, the signal was dominated by a large extensional mode with little flexural mode component detected by the conventional crossing threshold signal method with Wideband sensors. The results make clears that the location obtained by the resonant R15 sensors are superior to these obtained by wideband sensors. All impacts generated very large amplitude AE signals, which propagated as plate modes. The signals also consisted of much higher Frequency. The multi-source impact simultaneously was observed during the impacts in that it is difficult for the current conventional localized-algorithm to locate the sources.

1. INTRODUCTION

In last few decades, the mankind space exploration has result in the rapidly increase of Man-made orbit debris which threats the function and the health of the spacecrafts. All kinds of method has been investigated by many researchers to detect the sub-system and health of spacecrafts. Acoustic Emission (AE) detecting technique has been recognized as an important technology for non-destructive detecting due to the AE signals offering a potentially useful an additional means of non-invasively gathering concerning the state of spacecrafts. Also, Acoustic emission health monitoring is able to detect, locate, and assess impact damage when the spacecrafts is impacted by hypervelocity space debris and micrometeoroids. This information can help operators and designers at the ground station take effective measures to maintain the function of spacecraft. Many investigation concerning Acoustic Emission Application for to Columbus Module were carried out in the early 1990's by Det Norske Veritas in an ESA contract. A total of 12 ultrasonic transducers were located on the Columbus Shell. The impact localization accuracy was about 0.4m. Frank Schafer and Rolf Janovsky investigated the source location and impact signals of a 2mm thick Al-alloy panel and a 49mm thick Al-honey comb sandwich panel. They gave the results of the predicted and the actual experimental values for the impact location. The location accuracy of the Al-alloy panel is prior to that of Al-honey comb due to the anisotropic property.

2. HIGH-VELOCITY IMPACT TEST

A two-stage light gun was used for high-velocity impact experiments. The layout of the setup is shown in Fig 1. These high-velocity impacts cause damage, which more closely simulates that caused by hypervelocity impacts of micrometeoroids and space debris on spacecraft. The velocity of a projectile is affect by a lot of factors such as the projectile, weight, the pressure of the light gas in the first stage.

Fig.1 Setup of Two-state light gas gun

Fig.2 Layout of Acoustic Emission sensors

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Fig.3 Setup of PAC AE system

Fig.4 AE sensors and pre-amplifier

The gun was used to fire a 6.35mm and 3.97mm diameter spherical Aluminum spherical Aluminum ball at various impact velocities on to the Aluminum panels. To fire the balls, the chamber is pressurized to a prescribed level and then the trigger value is released. By varying the pressure in the first stage, the velocity of the ball is regulated. For these experiments, Impact tests were performed on each of Al-Alloy panels with lateral dimensions of 200x200mm and 1mm thickness. In the case, four sensors can be located any where at(0,0), for sensor 0,(x_1, y_1) for sensor 1,(x_2, y_2) for sensor 2, and(x_3, y_3)for sensor 3.The source is located at (x, y) which is an unknown location as shown in Fig5. Note that the locations of sensors do not have to form a rectangle shape with the source. They can be any where on the place. The ordinate of the source (x, y) are given by:

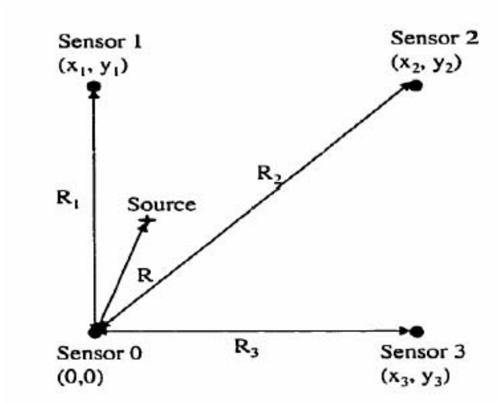


Fig.5 Four Sensor Array

$$x=\frac{\left[\left(R_1^2-V^2t_1^2\right)\left(y_2t_3-y_3t_2\right)+\left(R_2^2-V^2t_2^2\right)\left(y_3t_1-y_1t_3\right)\right]+\left(R_3^2-V^2t_3^2\right)\left(y_1t_2-y_2t_1\right)}{2\left[t_1\left(x_2y_3-x_3y_2\right)+t_1\left(x_3y_1-x_1y_3\right)+t_1\left(x_1y_2-x_2y_1\right)\right]V}\cdot\cdot$$

$$y=\frac{\left[\left(R_1^2-V^2t_1^2\right)\left(x_3t_2-x_2t_3\right)+\left(R_2^2-V^2t_2^2\right)\left(x_1t_3-x_3t_1\right)+\left(R_3^2-V^2t_3^2\right)\left(x_2t_1-x_1t_2\right)\right]}{2\left[t_1\left(x_2y_3-x_3y_2\right)+t_1\left(x_3y_1-x_1y_3\right)+t_1\left(x_1y_2-x_2y_1\right)\right]V}\cdot\cdot$$

$$R=\frac{\left[\left(R_1^2-V^2t_1^2\right)\left(x_2y_3-x_3y_2\right)+\left(R_2^2-V^2t_2^2\right)\left(x_3y_1-x_1y_3\right)+\left(R_3^2-V^2t_3^2\right)\left(x_1y_2-x_2y_1\right)\right]}{2\left[t_1\left(x_2y_3-x_3y_2\right)+t_1\left(x_3y_1-x_1y_3\right)+t_1\left(x_1y_2-x_2y_1\right)\right]V}$$

Where R is the distance from the source to sensor 0, R_i is the distance from the source1; Where i is 1 to 3, V is the speed of AE pulse, and the time duration required for the stress wave to travel from the source to sensor 0,1,2, and 3 are t, $t+t_1$, $t+t_2$ and $t+t_3$ respectively.

The solutions from the four-sensor can be used in dependently to check the validity of the data. The condition is that the solution (x, y), and R obtained must satisfy the relation: $x^2+y^2=R^2$

4. LOCALIZATION/RESULTS

The actual impact location is seen in Fig.6. The velocity of AE pulse is 6km/s obtained by measurement in agreement with the theoretic value. Tab.1 shows the actual experimental source location for R15 and Fig.5 for WD sensors. It is seen that the location accuracy for R15 is more excellent than WD sensors. For R15 sensors, the predicted impact location has maximum error about 13.03mm, 23.47mm for WD sensors. Fig.8 shows the frequency response of WD sensors and R15 sensors to the impact. Frequency response shows that both sensors can get the much higher peak amplitude due to the high energy. There exist many frequencies in the power frequency of WD sensors than in that for R15.The differences are due to the higher resonant response of R15 sensors. From the previous results of the source impact location, R15 sensors are generally used locate the impact source with high response amplitude. However, These WD sensors provide flat with frequency, high-fidelity displacement response, far off their resonance in the low-frequency range, which are often used to record the acoustic Emission for waveform analysis (Prosser, 1999).

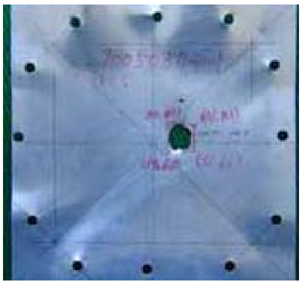
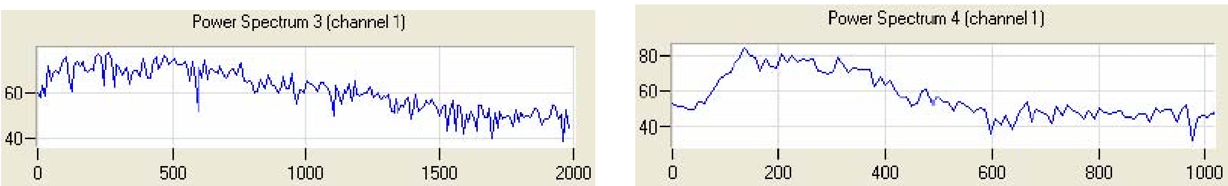


Fig.6 Result of Source location

Fig.7 Multi-source impacts

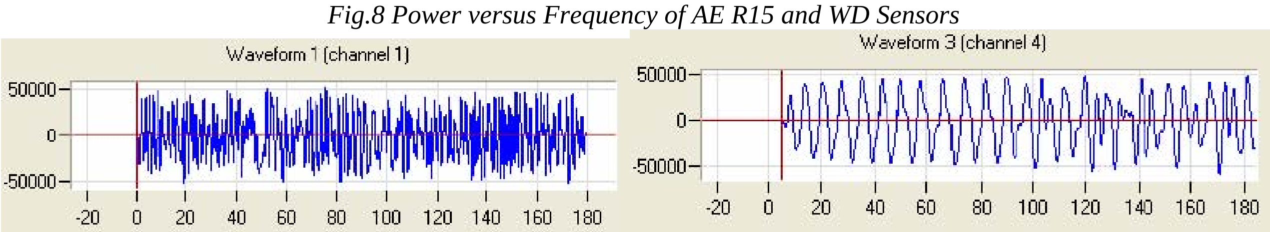
Table.1 Results of source location

No. of Exper.	**Predicted**		**Experiment**		**Error**		**Kind of Sensor**
	x_0	y_0	X	y	$\Delta\lvert x_0 - x\rvert$	$\Delta\lvert y_0 - y\rvert$	R15
1	85.89	25.99	80	46	5.89	20.01	R15
2	33.97	74.67	47	87	13.03	12.33	R15
3	92.32	69.80	92	70	0.32	0.20	R15
4	72.80	94.29	73	94	0.20	0.29	R15
5	79.92	39.33	78	42	1.92	2.67	R15
6	49.64	74.35	52	73	2.36	1.35	R15
7	25.24	89.19	25	80	0.24	9.19	WD
8	55.43	49.37	61	50	5.57	0.63	WD
9	80.85	35.77	76	41	4.85	5.23	WD
10	36.53	129.6	60	108	23.47	21.6	WD



（a） Power versus Frequency of WD （b） Power versus Frequency of R15

Fig.8 Power versus Frequency of AE R15 and WD Sensors



（a） Waveform of WD （b） Waveform of R15

Fig.9 Waveform of AE R15 and WD Sensors

5. IMPACT WAVEFORM

For these experiments, there were all impacts that fully penetrated the Al-plate. All impacts which propagated as plate mode had very large aptitude AE signals as above mentioned signals caused by high-velocity impacts that penetrated the Al-plate consisted of a large extensional component with little flexural modes. These results are agreed with those obtained by William H. Prosser (1999).

Another interesting problem was seen during these experiments. The nylon clip and the ball projector separated from each other and impacted on the Al-plate simultaneously, shown in Fig.7. In the case, only one location result was obtained for the multi-source impact. This kind of multi-source impact simultaneously may simulate the blast of space debris and micrometeoroids on the spacecraft, Current Acoustic Emission technique can't effectively deal with the multi-source location. Previously researchers have focused on the topic with blind source location arithmetic. Future effort will resolve the problem and make widely used in practice.

6. SUMMARY

This paper presents the results of source impact localization with resonant R15 and WD AE sensors. The location accuracy of the F15 sensors has less error than that of WD sensors. However, the WD sensors can record the more real signals in order to analysis by wave form analysis, Signals caused by high-velocity impact that all penetrated the Al-plate contained large amplitude extensional mode component and little flexural component. This indicates that there are more advantages to use resonant sensor for source location, and WD sensors for recording signals. The characteristics of signals can serve as a mode to identify the kind of impacts.

Another problem that was encountered during the experiments is the location of multi-source impact. Poor location accuracy of this impact was obtained by the current AE location arithmetic. Blind locations Arithmetic is being investigated by many researchers for solving this kind problem. This task is in progress with our work.

7. ACKNOLEDGEMENT

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8. REFERENCES

Willian H.Prosser, Michael R. Gorman and Donald H.Humes. Acoustic emission signals in thin plates produced by Impact Damage. Journal of Acoustic Emission, Vol.17(1-2)(June, 1999),pp.29-36.

R. J. KURTZ, D. K. LEMON, J.F. DAWSON, P. H. HUTTON, R. S. BARGA Acoustic Emission Applications on the NASA Space Station by M. A. FRIESEL, Volume 11A.725-732

Frank Schafer,Rolf Janovsky.Impact Sensor Network for Detecting of Hypervelocity Impacts on Spacecraft.IAC-04-IAA.5.12.2.04,55th International Astronautical Congress2004, Vancouver, Canada.

Yajai Promboo. Acoustic Emission Source Location. Dissertation for Degree of Doctor of Philosophy.2000.

Joe Chieh Chen, Wideband Source Localization Using Passive Sensor Arrays. Dissertation for Doctor.2002.