DAMAGE DETECTION IN COMPOSITE PLATE ARMOR USING ULTRASONIC TECHNIQUES (U)

Thomas J. Meitzler, Ivan Wong, Darryl Bryk, Thomas Reynolds, Sam Ebenstein
US Army RDECOM-TARDEC Survivability Research
Warren, MI, 48397-5000

(U) ABSTRACT

(U) A method for crack and damage detection in ceramic composite plate armors is presented. The method uses embedded piezoelectric Lead Zirconate Titanate (PZT) transducers to characterize the vibrational modes of composite armor plates. The amplitudes of the vibrational modes of damaged and undamaged plates are shown to be distinct. The differences in the vibration modes can be exploited to detect cracks and damage. Composite armor plates for testing are damaged by impact with a certain caliber round. Data from these tests can be used to design a vehicle based system for the nondestructive testing (NDT) and health monitoring of the armor plate structural integrity.

(U) Introduction

(U) This paper describes a new type of armor called **S**ensor **E**nhanced **A**rmor (SEA). The traditional method for evaluating armor health is visual inspection. This can be dangerous during combat situations. In addition armor can be damaged internally (for example the armor plate can be damaged in a minor collision) and a visual inspection may not reveal any damage. Our method relies on attaching embedded transducers to an armor plate. The armor plate is then subjected to ultrasonic vibrations of varying frequencies.

(U) The response curve for an undamaged plate is quite different from that of a damaged plate. By storing the results for the undamaged plate we have a baseline which represents a healthy plate. At any time in the future we can retest the plate. If the results of the retest differ greatly from that of the healthy plate we can conclude that the plate has been damaged. We are working on an algorithm and metric to be able to precisely measure the differences between a healthy and a damaged armor plate without a need for human inspection.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE
17 AUG 2009

2. REPORT TYPE
N/A

3. DATES COVERED

4. TITLE AND SUBTITLE
Damage Detection in Composite Plate Armor Using Ultrasonic Techniques (U)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
; ; ; ; Meitzler Thomas J.Wong IvanBryk DarrylReynolds ThomasEberstein sam

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
19980

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
TACOM/TARDEC

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
A method for crack and damage detection in ceramic composite plate armors is presented. The method uses embedded piezoelectric Lead Zirconate Titanate (PZT) transducers to characterize the vibrational modes of composite armor plates. The amplitudes of the vibrational modes of damaged and undamaged plates are shown to be distinct. The differences in the vibration modes can be exploited to detect cracks and damage. Composite armor plates for testing are damaged by impact with a certain caliber round. Data from these tests can be used to design a vehicle based system for the nondestructive testing (NDT) and health monitoring of the armor plate structural integrity.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**6**	

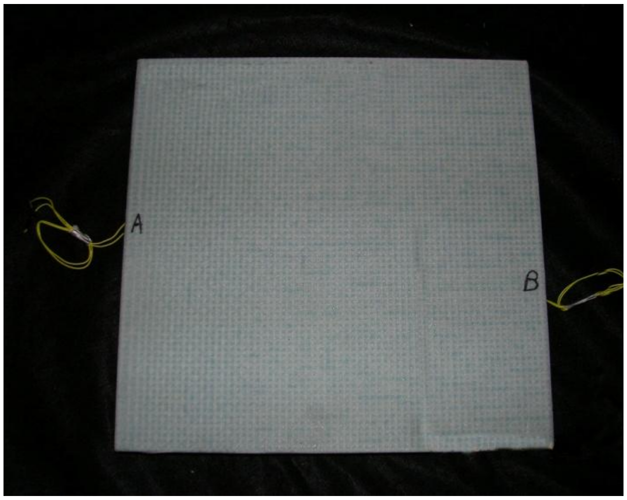

Figure 1. (U) Armor Plate with Embedded Sensors

(U) <u>General Description of the Method</u>

- (U) Ultrasonic sensors are bonded to the armor plate. A signal generator is then used to pass electronic signals of varying frequencies through these sensors. The reaction of the plate can then be recorded on a computer. A computer program was written to control the excitation of these sensors and analyze the signals that are returned from passing through the plate. Data is then collected by the following method: An ultrasonic signal is sent through the plate at frequencies varying from 1 kHZ to 200 kHZ. A signal is sent from sensor A in Figure 1 and is received at sensor B. The strength of the signal received at B depends upon the voltage of the input signal and the physical properties of the plate. The input signal is always of the same strength, but there will be differences in the amplitude of the output signal because the plate is more sensitive to some frequencies than others. By this method 200 data points are collected from each test, one for each frequency. The placement of the sensors is important because it has an effect on the plate's vibration. The sensors can be placed on either the top surface of the armor plate or in the sides of the plate as in Figure 1.

- (U) The test is then repeated several times under varying environmental conditions such as temperature and humidity to collect data which are the basis for the plate's signature when it is in a "healthy" or undamaged state. The plate should be tested at least 10 times to provide a good baseline. Each test gives a vector of 200 points, and we can average the data from several tests to get the general shape of the curve of a healthy plate. The equation which can be used to define the representative curve is as follows:

$$x(i) = \frac{1}{n}\sum_{j=1}^{n} y_j(i)$$

where $x(i)$ is the i^{th}coordinate of the representative curve and $y_j(i)$ is the i^{th} coordinate of $y_j(i)$ where j represents the j^{th} test, and i varies between 1 and 200.

- (U) Similarly the standard deviation at each point i is defined by

$$\sigma(i) = \sqrt{E[y(i)^2] - E[y(i)]^2}$$

where E denotes expected value.

- (U) At some later time we can retest the plate to see if it has changed. We can then compare the data from the retest to the known good data to determine if the plate is still healthy.

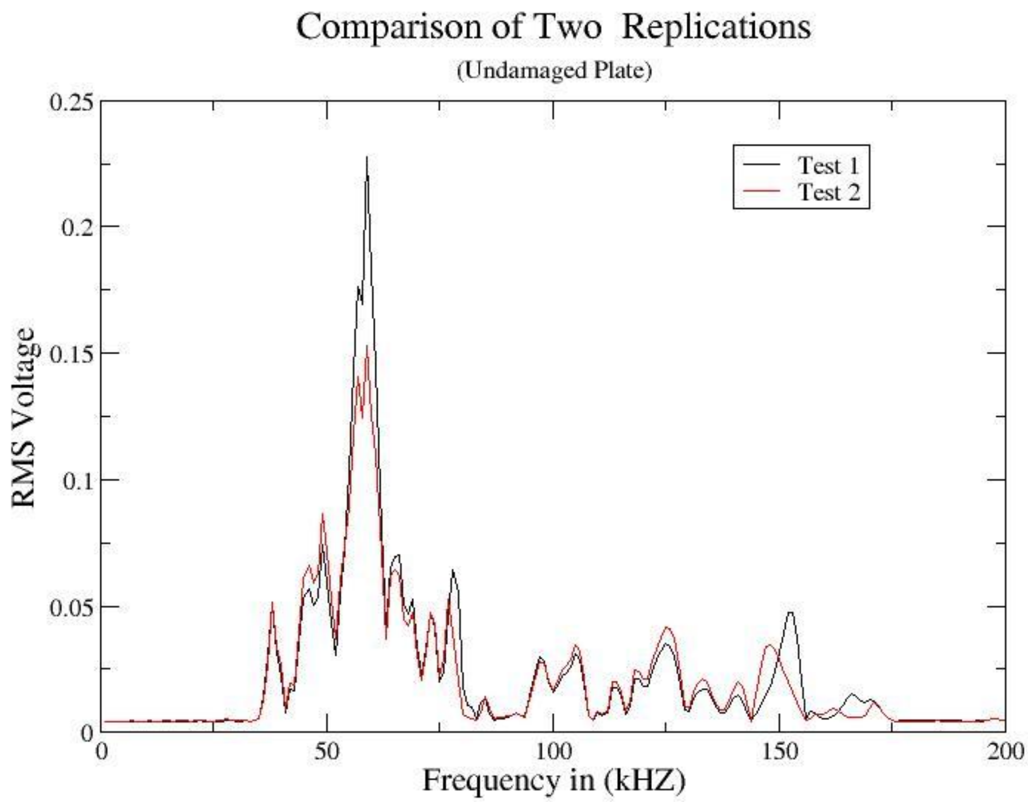

Figure 2. (U) Comparing Two Replications of Testing an Undamaged Plate

(U) Figure 2 shows the two replications on the same graph.

(U) The photograph in Figure 3 shows the results of impacting an armor plate with a ballistic round.

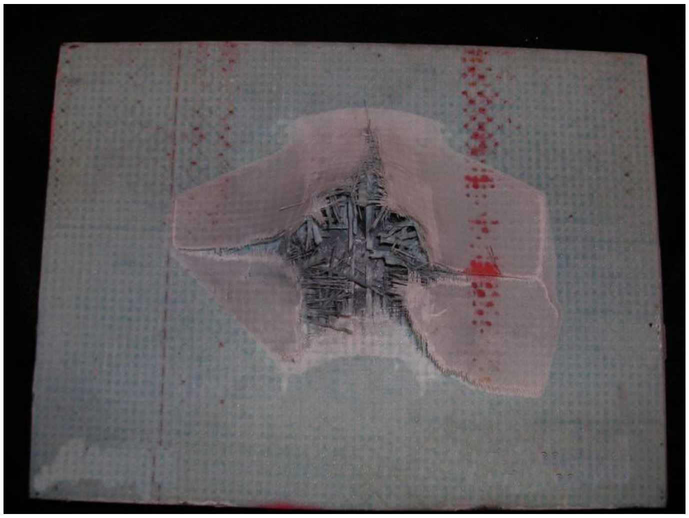

Figure 3. (U) Plate after Impact

(U) Figure 4 shows the results of two replications of the damaged plate.

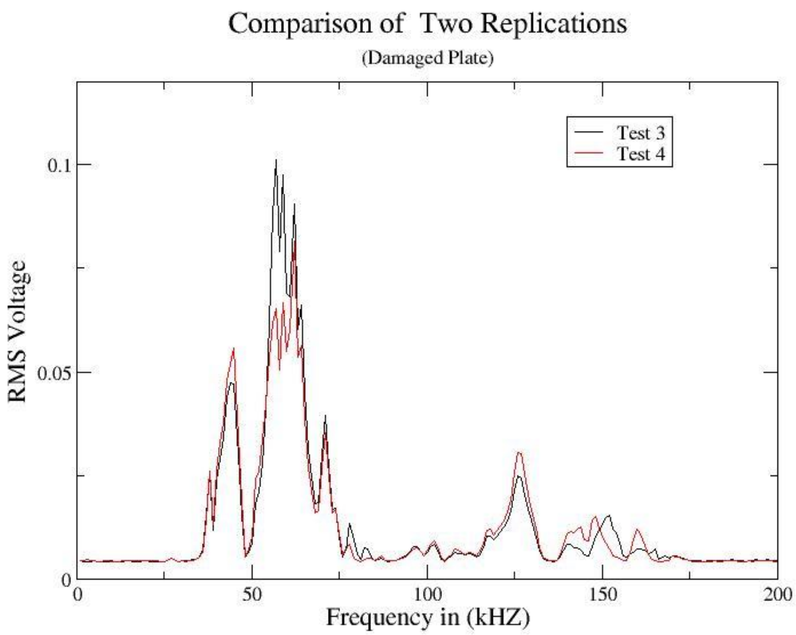

Figure 4. (U) Comparing Two Replications of Testing a Damaged Plate

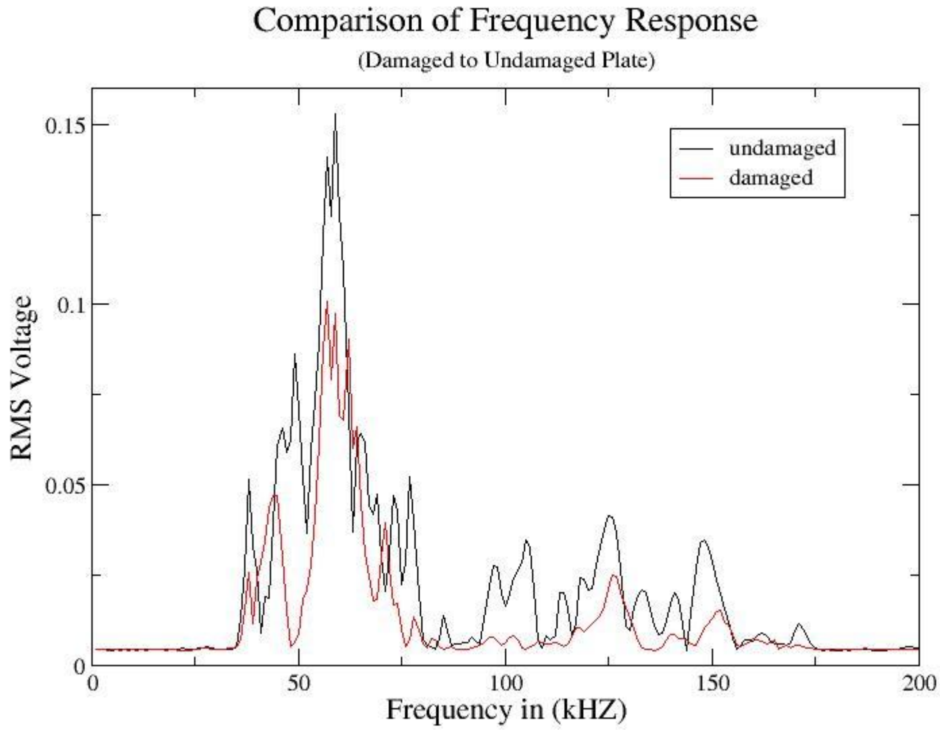

Figure 5. (U) Comparing the Frequency Response of a Damaged Plate to an Undamaged Plate

(U) Figure 5 shows that the response of a damaged plate differs quite a bit from that of an undamaged plate in several frequencies. In particular we can observe that for frequencies over 100 kHZ the undamaged plate displays many more peaks than the damaged one. We are working on a metric that will more precisely measure the differences in frequency response between a damaged and undamaged plate. This will permit the determination of armor health without human intervention.

(U) <u>Conclusions</u>

(U) The authors have demonstrated how ultrasonic signals generated by piezoelectric transducers can be used to provide real-time health monitoring for a class of armor known as ceramic composite armor. Future work will entail extending this technique to other armor designs and optimizing the sensor system design.

(U) References

[1] Meitzler, T., Smith, G., Wong, I, Charbeneau, M., Sohn, E., Bienkowski, M., and Meitzler, A., "Crack Detection in Armor Plates Using Ultrasonic Techniques," American Society for Nondestructive Testing, Materials Evaluation, Vol. 66, no. 6, pp. 555 – 559, June 2008.

[2.] A. Leissa, ***Vibration of Plates,*** Acoustical Society of America, 1993, originally issued by NASA, 1973.

[3.] H. M. Evans, US Patent 4,519,245, "Method and apparatus for the non-destructive testing of materials," May, 1985.

[4.] C. Hellier, ***Handbook of Nondestructive Evaluation***, McGraw-Hill, New York, 2001.