

# Non Destructive Testing of Body Armor Plates for Structural Integrity

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# Ceramic Armor Plate



Strike face

Component to be tested

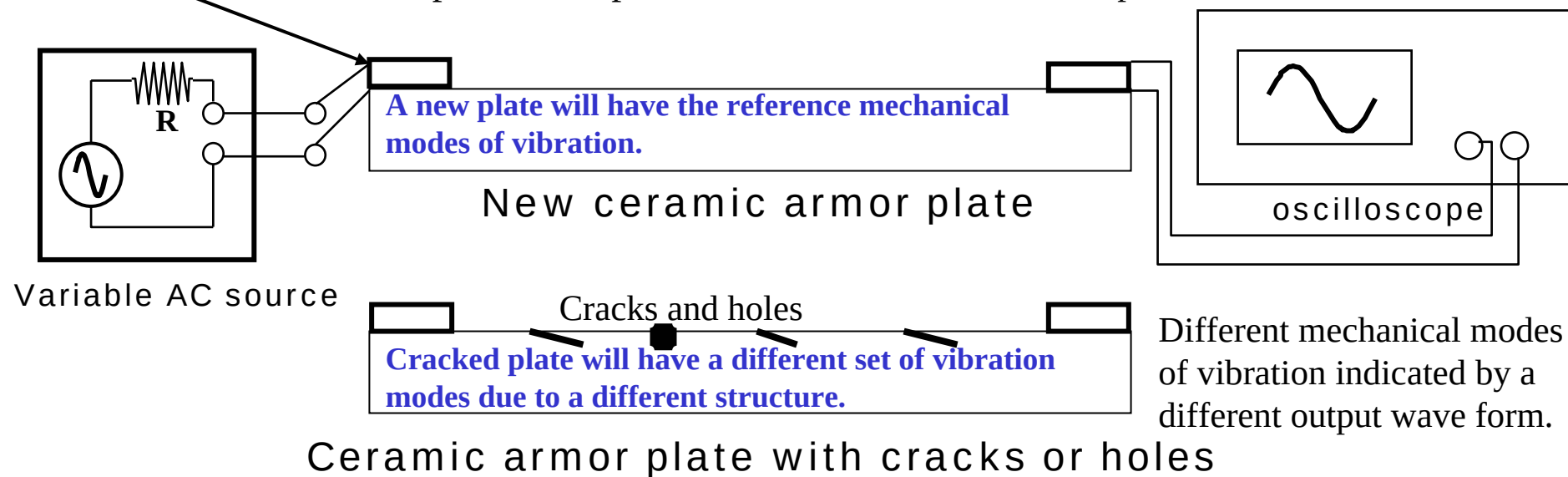
The outer strike plate is the component in the armor whose structural integrity is needed to be known. The test method described has been demonstrated on body armor plates at TARDEC and will also be effective on plates that are deployed in the field using a modified test procedure.

# Ceramic Plate Vibrational Mode Identification Using Piezoelectric Sensors

Principle: An AC voltage will cause the piezoelectric transducer to vibrate and this vibration when coupled to the ceramic plate will excite a resonant mode in the plate which can then be measured by another transducer.

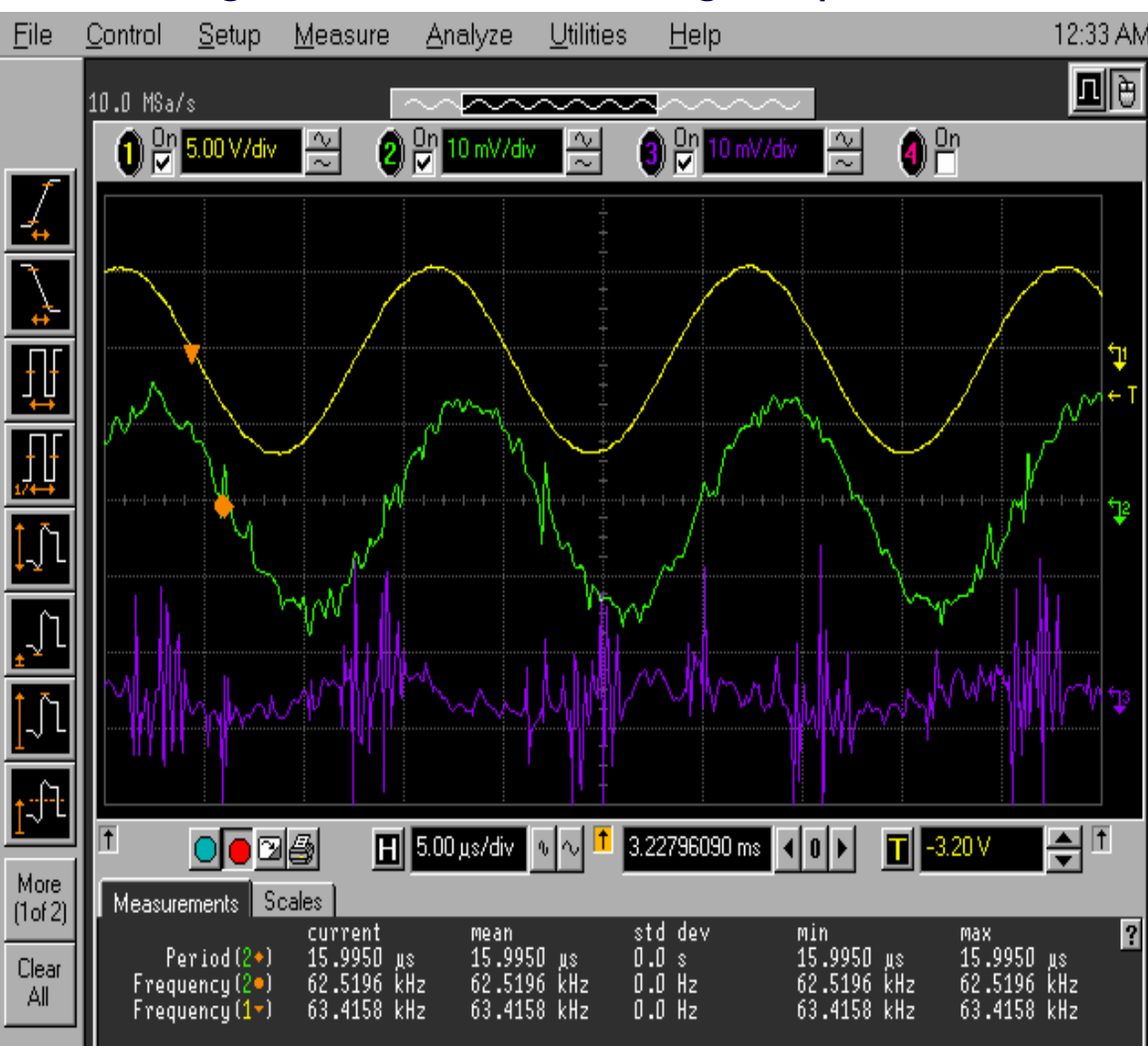
Various input voltage signals excite the transducer and are coupled to the plate

Output voltage from the transducer caused by the mechanical oscillation of the plate will be used as the standard for comparison.



***This test configuration will show a profound change of the amplitude of the transmission signal if the plate is cracked.***

## Damaged and undamaged plate fundamental harmonic



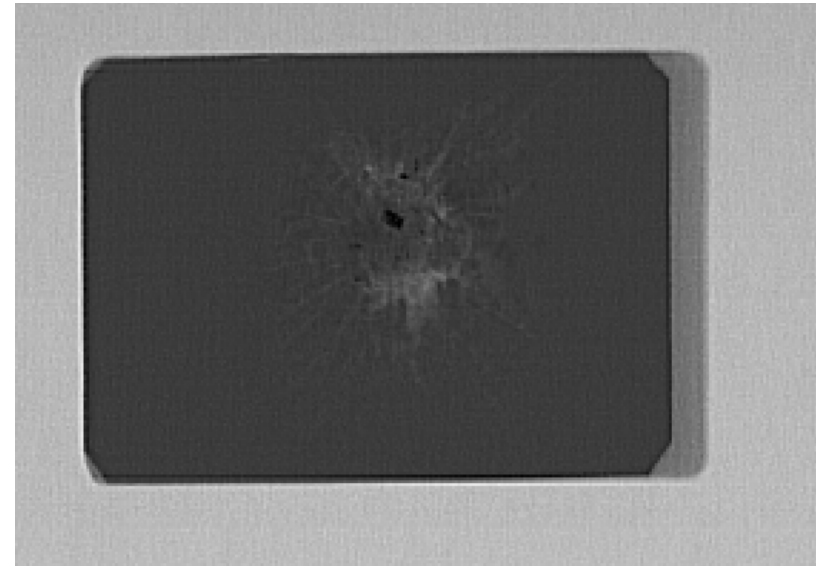
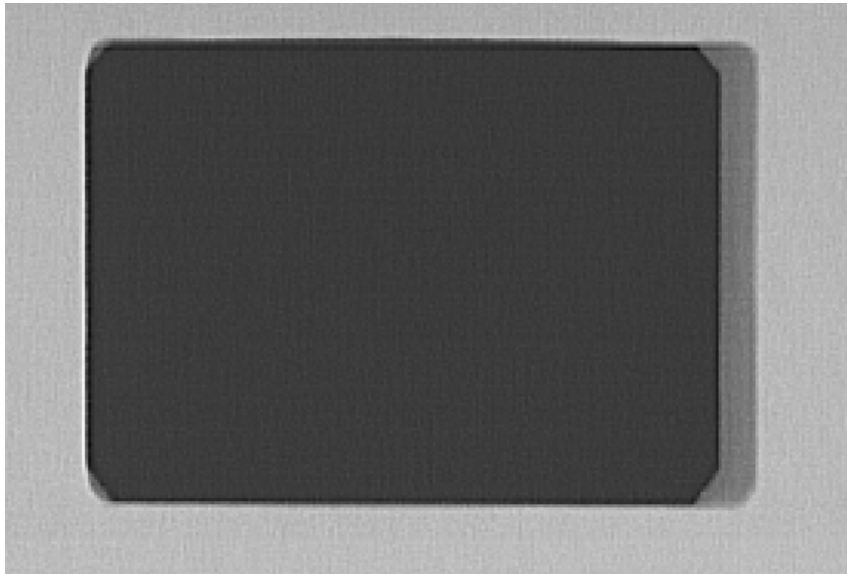
Signal 1 = driving signal of transducer

Signal 2 = resonant vibration of undamaged plate

Signal 3 = resonant vibration of plate cracked and with one small hole

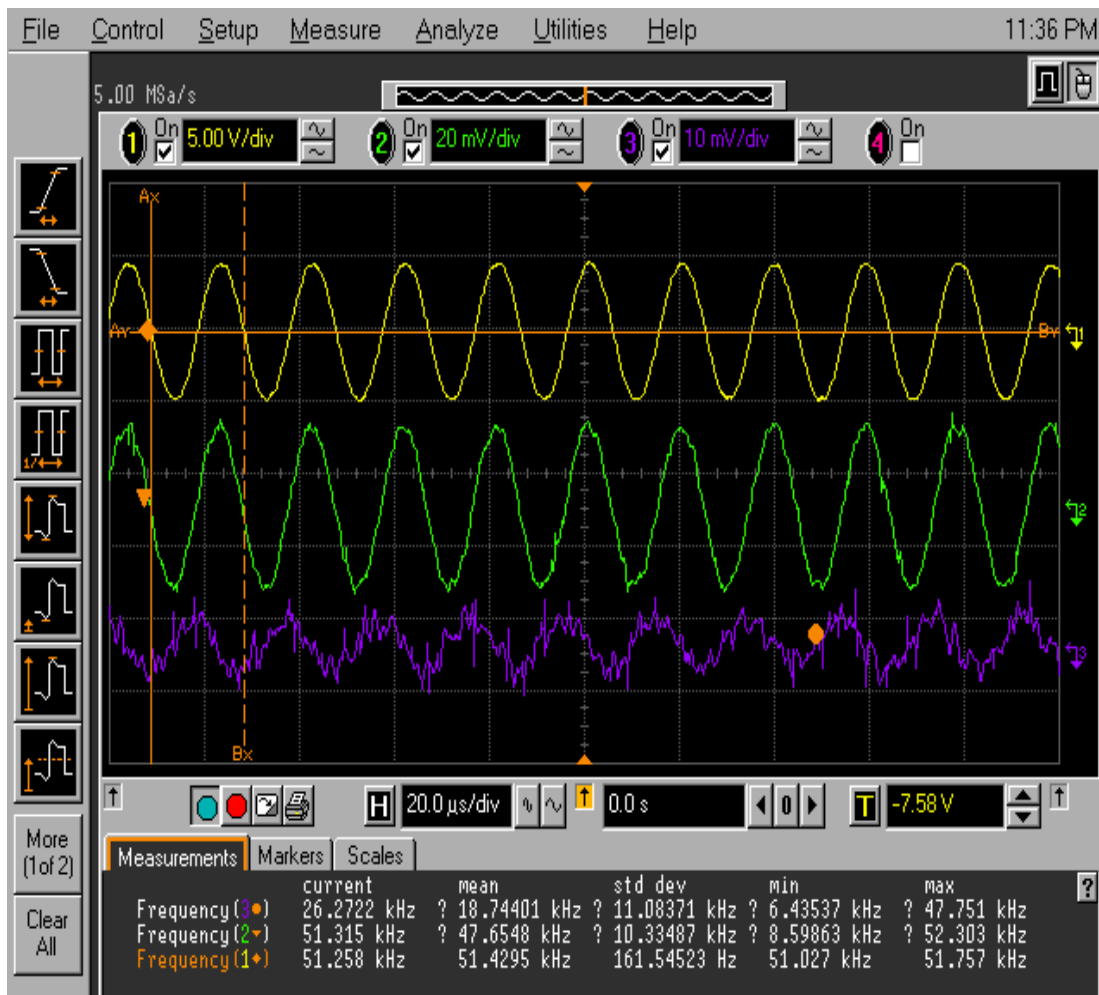
***The amplitude and the envelope of the damaged plate is very different.***

X-ray images of undamaged and a plate with a hole and many cracks





## Undamaged and cracked plate vibration modes



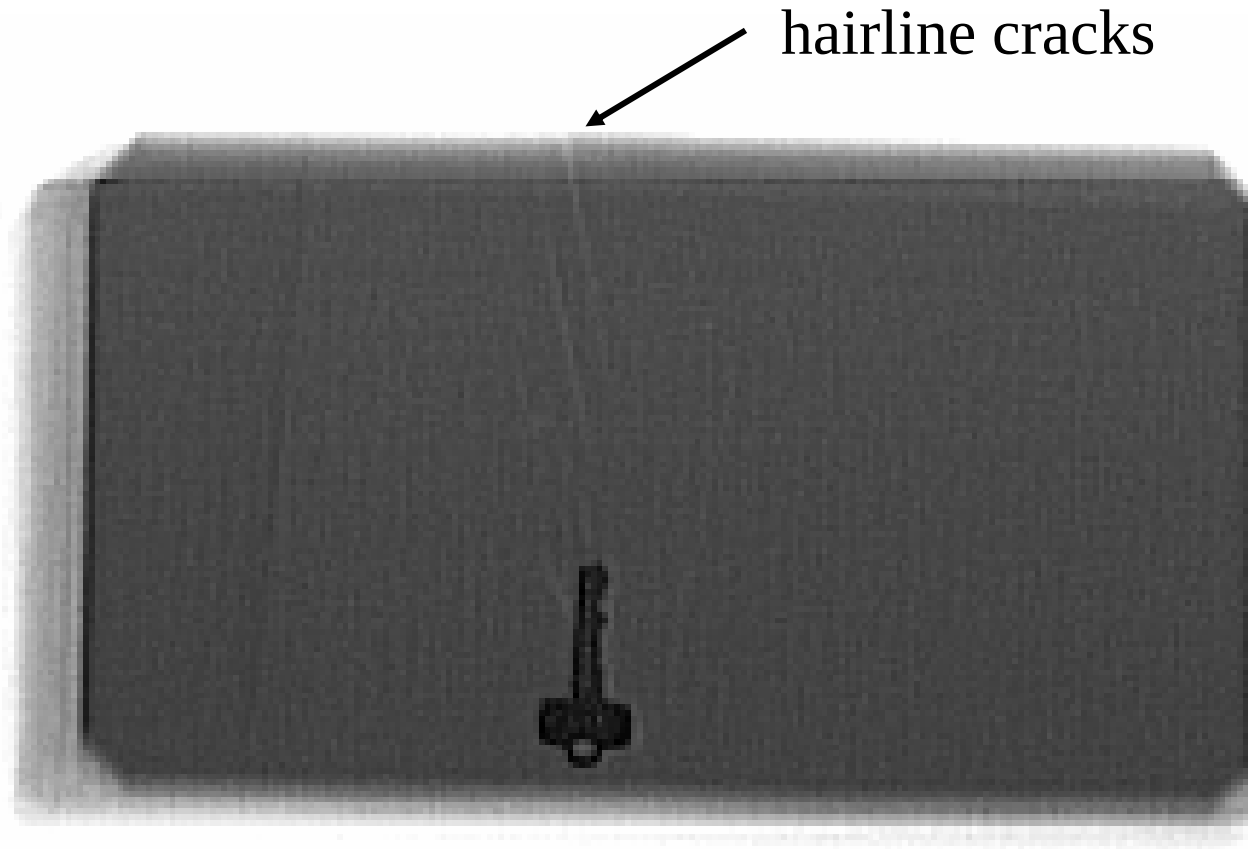
Signal 1 = driving signal of transducer

Signal 2 = resonant vibration of undamaged plate

Signal 3 = resonant vibration of cracked plate

*The amplitude from the cracked plate is reduced by factor of 4 and has a significantly different envelope.*

## X-ray image of cracked plate



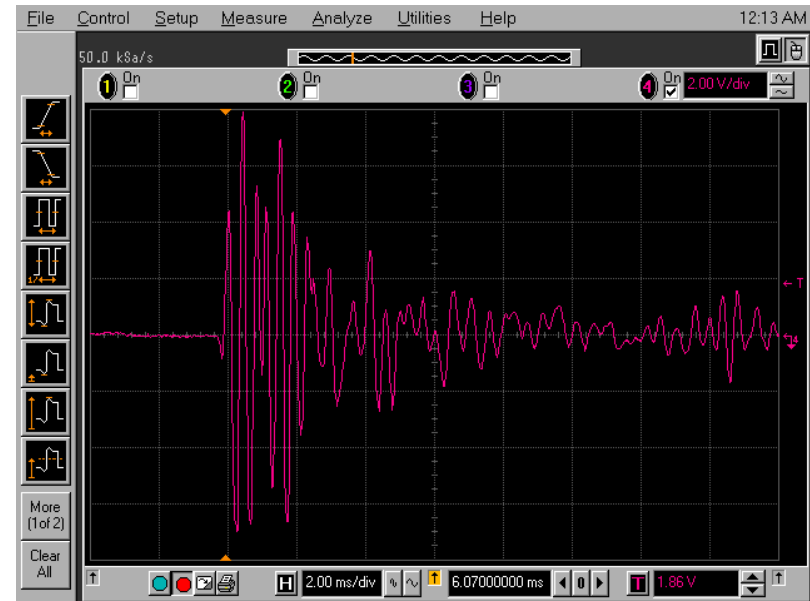
*The crack is barely visible with the x-ray but it shows up well by comparing the modes of vibration of the uncracked and cracked plates.*



## Undamaged and cracked plate using impulse excitation for future field test unit



uncracked



cracked

*The “ring” of the cracked plate is very different from the uncracked plate. The plates were tapped and then recorded.*

## Non Destructive Testing of Armor Plates Using a Mechanical Impulse and Piezoelectric Vibration Sensor

- While the method sounds complex, it is very much like tapping a watermelon to see if it is ripe. We are developing a sensor that will deliver a light tap to a plate under test and “listen” to the resulting vibrations with a piezoelectric sensor that is in contact with the plate.
- Our preliminary tests have shown that a damaged plate (even one with just a hairline crack) gives a very different vibration response compared to that from a undamaged plate in terms of both its resonant vibration modes and impulse response.
- We envision a hand held device that would have the signal processing on board and would give a pass/fail indication to the user immediately.
- A MEMS processor will be connected to the transducers to perform the required FFT power spectrum analysis.

# Program Goals

- We have identified the resonant vibrational modes of undamaged and cracked VBASS armor plates and can distinguish the two using lead zirconate titanate (PZT) piezoelectric transducers.
- We are in the process of building a hand-held prototype to perform the testing of vest armor plates.
- The current proof of principle device will be for the VBASS plates only since that is all we have for testing purposes.
- We want to obtain the actual plates that are currently used in the field for vest armor and modify the prototype field unit's profile as needed.
- Long term plans are two-fold:
  1. Continue characterizing the vibrational modes of plates in the lab.
  2. Determine how many types of armor can be programmed into the field unit.
  3. Consider the possibilities for the transducers to be built in to the armor for “plug-and play” testing in the future.

## Plate Vibration Theory (Leissa 1969, NASA SP-160)

*The equation that describes the vibration of a plate is*

$$D\nabla^4 w + \rho \frac{d^2 w}{dt^2} = 0,$$

*where  $D$  is the plate stiffness defined by,*

$$D = \frac{Eh^3}{12(1-\nu^2)}.$$

*$E$  is Young's modulus,  $h$  is the plate thickness,*

*$\nu$  is Poisson's ratio, and  $\rho$  is the mass density per unit area of the plate.*



*The solution to this equation of motion are the frequencies of vibration of the plate,*

$$\omega_{mn} = \sqrt{\frac{D}{\rho}} \left\{ \left( \frac{m\pi}{a} \right)^2 + \left( \frac{n\pi}{b} \right)^2 \right\}.$$