The generated electrical signal of piezoelectric sensor by a single pulse

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Abstract. The objective of this study was to study the generated electrical signal of piezoelectric sensors patched on the various samples by using one single pulse. Piezoelectric sensors used in this study were the commercial piezoelectric buzzers which are PZT ceramic disk of 20 mm with brass plate of 27 mm in diameter. The generated electrical signals of piezoelectric sensors from aluminium plate, acrylic plate and wood plate were compared in this study. The experimental result is expected to explain physical mechanism for structural health monitoring application.

1. Introduction
Piezoelectric materials can transform mechanical energy into electrical energy or vice versa [1]. These materials are useful for various applications. One of the applications is sensor [2-3] where it transfers energy of the vibration into a signal which can be measured electrically. Advantages of piezoelectric sensor are inexpensive, small, light-weight, low power requirement, less sensitive to temperature variation and linear response under low electric field. Numerous researchers have been interested in extracting electricity from wasted environmental vibration. In this work, we will focus on the investigation of the electrical signal from the piezoelectric sensor by using stimulation in transient mode which is one single pulse and installation of piezoelectric sensor by patching on aluminium plate, acrylic plate and wood plate.

2. Methodology
In this work, the commercial piezoelectric buzzers [4] were used as sensor for electrical signal measurement by using stimulation in one single pulse. These piezoelectric buzzers which are PZT ceramic disk of 20 mm with brass plate of 27 mm in diameter were patched on surface of aluminium (acrylic and wood) plate and connected with oscilloscope for collection of electrical voltage from piezoelectric sensor and recorded by personal computer. Spacing of piezoelectric buzzers is 15 cm. The middle piezoelectric buzzer (sensor B) was patched in middle of the surface of the plate supported on a table through small sponge blocks for free vibration as shown in figure 1. In this experiment, we stimulated the surface of the plate in one single pulse by tapping at 6.25 cm from sensor A. The electrical voltage generated by piezoelectric sensor is the result of piezoelectric effect. The relationship between mechanical and electrical parameters for piezoelectric materials can be defined by the constitutive equations [5-6]
\[ S = s^E T + dE \]  
\[ D = dT + e^T E \]

where \( S \) is the strain, \( s^E \) is the compliance at constant electric field, \( T \) is stress, \( d \) is the piezoelectric coefficient, \( E \) is the electric field, \( D \) is the electric displacement (charge density) and \( e^T \) is the dielectric permittivity at constant stress.

The generated signal by impulse was the damped oscillation as shown in figure 2. The logarithmic decrement and damping factor can be calculated by the following equations

\[ n\delta = \ln \left( \frac{y_i}{y_{i+n}} \right) \]  
\[ \xi = \frac{\delta}{\sqrt{\left(2\pi\right)^2 + \delta^2}} \]

where \( \delta \) is the logarithmic decrement, \( n \) is the number of damped periods, \( y_i \) is magnitude of peak of \( i \), \( y_{i+n} \) is magnitude of peak of \( i + n \) and \( \xi \) is the damping factor.

3. Results and discussion

The measured electrical signals of piezoelectric buzzers from aluminium plate, acrylic plate and wood plate are shown in figure 3. The magnitude of signal peak decreases with time. The first main peak signal of the patched piezoelectric buzzers (sensors) on aluminium plate is stronger than acrylic plate and wood plate by the same tapping. The free vibration of plates in steady state has the different frequencies. Frequency of aluminium plate is 22.11 Hz which is higher than the wood and acrylic plates (15.98 Hz and 13.80 Hz, respectively). The electrical signals of piezoelectric buzzers are normalized to show the change of the signal more clearly as shown in figure 4. It can be seen that the reduction of the signal of aluminium plate is reduced faster than the wood plate and acrylic plate. It clearly indicated that the measured electrical signal was the damped oscillation when we used the magnitude of each peak to determine the behavior of damped oscillation. The behaviors of oscillation were the exponential decay in form of single exponential decay in equation (5) and double exponential decay in equation (6).

\[ y = B_0 + A_0 e^{-\beta_0 t} \]  
\[ y = A_1 e^{-\beta_1 t} + A_2 e^{-\beta_2 t} \]

where \( A_0 \) is amplitude, \( B_0 \) is the constant, \( \beta_0 \) is decay constant (logarithm decrement), \( A_1, A_2 \) are amplitudes in transient state and steady state respectively and \( \beta_1, \beta_2 \) are decay constants (logarithm
decrement) in transient state and steady state, respectively. The behaviors of oscillation from all sensors A are the double exponential decay because these sensors are near the tapping point. The behaviors of oscillation from sensors B and C are the exponential decay except the signals from sensor B and sensor C of aluminium plate are still the double exponential decay. This may be due to the fact that the propagation of wave in aluminium plate is better than other plates. In case of the double exponential decay, the fitting curves (envelope curve of measured signal) are shown in figure 5. So the reduction of envelope curve was separated into two regions. The first region is transient state when the envelope curve decreases rapidly. After that, it decays slowly in the second region (steady state). From fitting curve, the logarithm decrements of aluminium plate, acrylic plate and wood plate in the steady state (second region) are 2.1142, 3.6034 and 2.1271, respectively. In order to compare with the theory, the logarithm decrements calculated from equation (3) are 2.1489, 4.4463 and 2.1919 for aluminium plate, acrylic plate and wood plate, respectively. These values are consistent with the values from fitting curve except for acrylic plate. This may be effect of the sound velocity of acrylic which is less than others. Parameters of the fitting curve for all three sensors (A, B and C) are presented in table 1. The logarithm decrements are used to calculate the damping factors. From equation (4), the damping factors are 0.3189, 0.4975 and 0.3207 for aluminium plate, acrylic plate and wood plate, respectively. These values obviously indicate that it is underdamped oscillation because these values are less than one.

![Figure 3. The measured voltage of piezoelectric sensors from various plates](image1)

![Figure 4. The normalized voltage of piezoelectric sensors from various plates](image2)

| Plate   | Sensor | $y = A_1 e^{-\beta_1 t} + A_2 e^{-\beta_2 t}$ |
|---------|--------|---------------------------------------------|
|         |        | $A_1$ | $\beta_1 (s^{-1})$ | $A_2$ | $\beta_2 (s^{-1})$ | $R^2$ |
| Aluminium | A      | 17.3391 | 61.9630 | 0.0954 | 2.1142 | 0.99999 |
|          | B      | 13.7060 | 67.9635 | 0.3499 | 2.2623 | 0.99991 |
|          | C      | 5.5981  | 58.8872 | 0.5759 | 1.9728 | 0.99965 |
| Acrylic  | A      | 6.1946  | 44.3617 | 0.5202 | 3.6034 | 0.99945 |
|          | B      | -       | -       | 0.1405 | 1.6056 | 0.97414 |
|          | C      | -       | -       | 1.1813 | 3.7581 | 0.99204 |
| Wood     | A      | 86.1263 | 91.5348 | 0.2322 | 2.1271 | 0.99976 |
|          | B      | -       | -       | 1.4008 | 1.4471 | 0.99619 |
|          | C      | -       | -       | 1.1198 | 5.3936 | 0.98701 |
4. Conclusions
The piezoelectric buzzer can be used as sensor for detection of signal by environmental stimulation. The generated electrical signal of piezoelectric buzzer patched on surface of aluminium plate, acrylic plate and wood plate by stimulation in single pulse is underdamped oscillation. The reduction of magnitude of signal peak (envelope curve) is in double exponential decay in case of aluminium plate. In acrylic plate and wood plate, envelope curves are in exponential decay except in sensor A and B are still double exponential decay due to these sensors are near the tapping point. In all sensors A, the behaviors of oscillation are double exponential decay. The reduction of magnitude of signal in transient state (the first region) decreases rapidly after that it decays slowly in steady state (the second region). The logarithm decrements are 2.1142, 3.6034 and 2.1271 for aluminium plate, acrylic plate and wood plate, respectively. The damping factors are 0.3189, 0.4975 and 0.3207 for aluminium plate, acrylic plate and wood plate, respectively. The free vibrations of plates are 22.11 Hz, 13.80 Hz and 15.98 Hz for aluminium plate, acrylic plate and wood plate, respectively.

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