*The 2015 World Congress on*
***Advances in Structural Engineering and Mechanics (ASEM15)***
*Incheon, Korea, August 25-29, 2015*

# Concrete cure monitoring using piezoelectric admittance measurements

* Wan Cheol Kim [1)] Hye Jin Jo [2)] and Gyuhae Park[3)]

[1), 2), 3)] *School of Mechanical Engineering ,Chonnam National University, Gwangju, Korea*
[3)] *gpark@chonnam.ac.kr*

## ABSTRACT

This paper presents a new concrete curing monitoring technique using embedded piezoelectric transducers via admittance measurements. When a piezoelectric transducer is embedded in a structure, the electrical impedance (admittance) of the transducers is coupled with the mechanical impedance of a host structure, which allows monitoring of the structural condition. In this study, the admittance signatures are extended to monitor the concrete curing process. This new method is based on an admittance-based sensor diagnostic process, in which the capacitive values of piezoelectric transducers are dependent on the strength of a host structure. We systematically investigated the slope variations of piezoelectric admittance as a function of curing status of concrete. The results demonstrate that there is a clear relationship between the concrete curing status and the slope, which indicates that this proposed method could be efficiently used to monitor concrete curing.

## INTRODUCTION

In recent years piezoelectric smart materials have been applied to curing monitoring of concrete structures through either electro-mechanical impedance (EMI) methods, or vibration characteristic-based method. For example, Shin et al (2007, 2009) implemented an experimental study on monitoring the strength gain in a continuous the EMI technique. Lee et al (2010) investigated the evolution of the EMI of PZT patch embedded in cement paste during setting process. However, these studies on monitoring the variation of resonant peak of EMI by curing process in the concrete structure have some disadvantages. There are multiple peaks exist in the measurement and it is not clear which resonant frequency would be most efficient for curing monitoring. The effects of existing structural damage must be considered when analyzing the results. In addition, it is not straightforward to estimate the final or optimal concrete curing status.

In this paper, we propose a new method to monitor concrete curing based on piezoelectric admittance measurements. The basis of this concrete cure monitoring procedure is to track the changes in the capacitive value of piezoelectric materials,

---

[1)] Student
[2)] Student
[3)] Professor

which shows in the imaginary part of the measured admittances. By monitoring the imaginary part of admittance value, it is possible to quantitatively assess the status of concrete curing process.

## ADMITTANCE-BASED CONCRETE CURE MONITORING

The curing monitoring is based on the sensor diagnostic process which utilizes the imaginary part of impedance (admittance) in the PZT transducer developed by Park et al (2006).

When a PZT transducer surface-bonded to a host structure, The electrical admittance $Y(\omega)$ of the PZT transducer is a combined function of the mechanical impedance of the host structure $Z_s(\omega)$ and that of the PZT transducer $Z_a(\omega)$, given by ;

$$Y(\omega)=i\omega \frac{wl}{t_c}\left(\varepsilon_{33}^T(1-i\delta)-d_{31}^2 Y_p^E+\frac{Z_a(\omega)}{Z_a(\omega)+Z_s(\omega)} d_{31}^2 \hat{Y}^E\left(\frac{\tan kl}{kl}\right)\right) \tag{1}$$

where $\omega$ is the angular frequency, $\delta$ is the dielectric loss tangent of PZT material. $w, l, t_c$ is the width, length and thickness of a PZT transducer, $Y_p^E$ is the complex Young's modulus of the PZT material at zero electric field, respectively.

A significant observation that can be made from (1) is that one can identify the effect of sensor condition on the measured electrical admittance. The effect of the bonding layer is obtained by letting $Z_s(\omega)$ be $\infty$ in Eq.(1).

$$Y(\omega)= i\omega \frac{wl}{t_c}\left(\varepsilon_{33}^T(1-i\delta)-d_{31}^2 Y_p^E\right) \tag{2}$$

$$=Y_{free}(\omega)- i\omega \frac{wl}{t_c}(d_{31}^2 Y_p^E)$$

It is clear from (2) that the electrical admittance of a PZT transducer would be different if under a free-free condition or surface-bonded condition. The bonding would cause a downward shift in the slope of the electrical admittance of a free PZT transducer with the factor of $d_{31}^2 Y_p^E$. In this study, this principle was used for monitoring concrete curing. As shown in Eq.(1), the imaginary electrical admittance $Y(\omega)$ could be represented as a function of structural impedance, $Z_s(\omega)$. As concrete curing progresses, structural impedance increases and it can be manifested as downward shifts of the slope in the electrical admittance of the PZT transducer.

## EXPERIMENTAL INVESTIGATION

Experiments were conducted to demonstrate the proposed method for monitoring concrete curing. As shown in Figure 1, the dimension of the concrete cube was $250\times 180\times 150$ (mm), fabricated with water-cement ratio, 0.4. Then several PZT transducers (copper-plate PZT) which had diameter 25 (mm) were embedded into the concrete cube. In order to protect the PZT transducers from water, they were covered with acryl coating (AC-100).

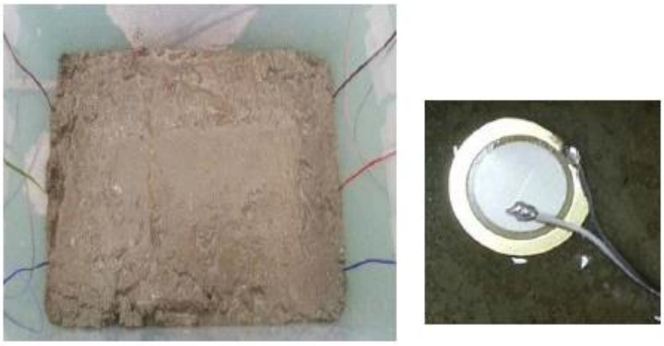

**Fig.1 Concrete cube and PZT transducer**

In order to measure the electrical admittance of the PZT transducers embedded into the concrete cube, an impedance circuit as shown in Figure 2 was used along with NI 4431 data acquisition device (Peairs et al. 2004). The admittances of six PZT transducers were measured in the frequency range of 0-20kHz. The experiment was continued until the curing process was complete with the admittance measurements made every 2hour.

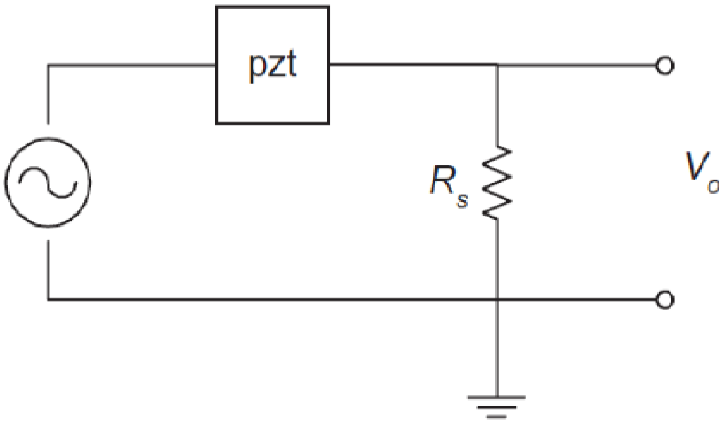


**Fig.2 Circuit of approximating PZT**

## EXPERIMENT RESULTS

The experiment was conducted to compare the electrical admittance slope of the PZT transducers under various conditions. Comparing to the slope measured under free-free condition, the slope measured at 0 hours was decreased by 11% as shown in Figure 3.

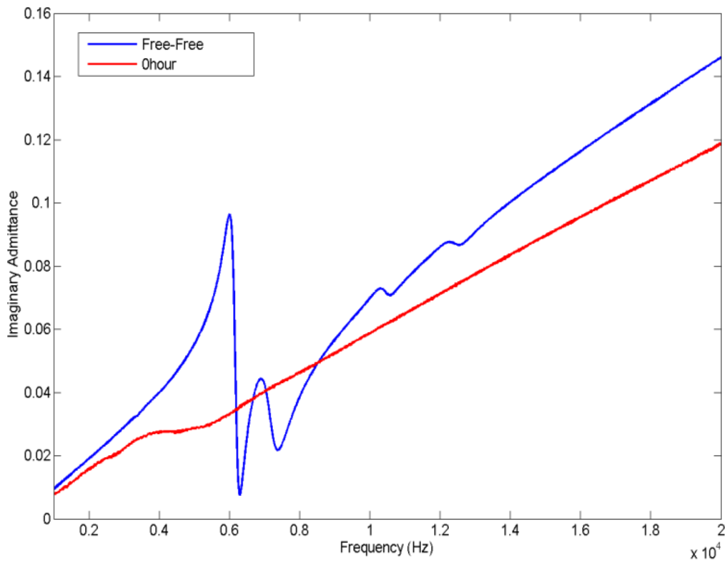


**Fig.3 Imaginary part of admittance under free-free condition and measured data at 0 hours**

During concrete curing process, the slope of the electrical admittance value gradually decreased as observed in Figure 4. This is because as the curing process progresses, the mechanical impedance of concrete increases. The results are the downward shift of the piezoelectric admittance. After 144 hours, the slope did not change and it converged to a certain value. Since there was no change in the slope after 144 hours, the concrete curing process was determined to be complete.

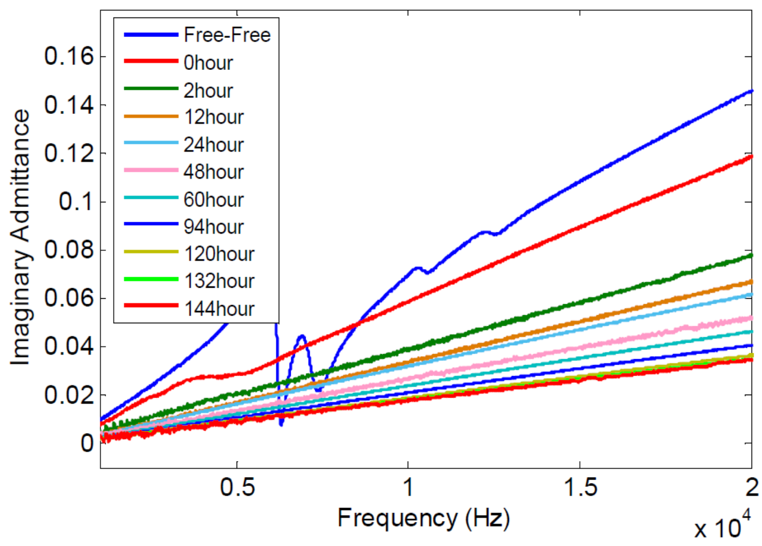


**Fig.4 Difference of admittance through each time progress**

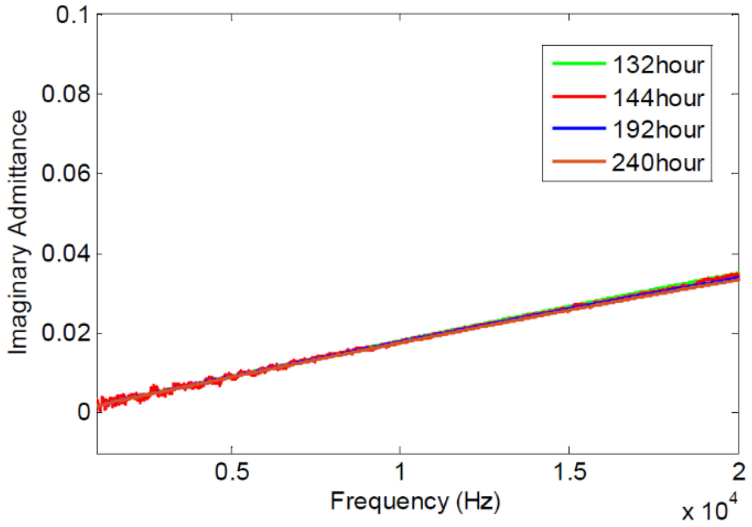


**Fig.5 Imaginary admittance after curing completion**

As shown, this method provides with several advantages compared to the previous methods based on EMI techniques. This method does not have to identify structural resonances or search for optimal frequency ranges for cure monitoring. Also, one can estimate analytically or experimentally the slope changes associated with complete curing. Furthermore, this method would require much lower frequency ranges compared to other methods. An extensive research works are planned to efficiently use the proposed methods for real-world field applications.

## CONCLUSION

This paper presents a new method of monitoring concrete curing using embedded piezoelectric transducers via admittance measurements. This method is extended from sensor diagnostic process based on admittance measurements. The results demonstrate that there is a clear relationship between the concrete curing status and the admittance slope, which indicates that this proposed method could be efficiently used to monitor concrete curing. Meanwhile, several experimental investigations will be conducted as future works. By using multiple PZT transducers located in a concrete structure, we will simultaneously monitor the curing status in various locations in a concrete structure. Analytical studies are also planned to understand the direct relationship between the concrete and admittance measurements.

## ACKNOWLEDGEMENTS

This work is partially supported by the Leading Foreign Research Institute Recruitment Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (2011-0030065).

## REFERENCES

Park, G., Sohn, H., Farrar, C. R., & Inman, D. J. (2003). Overview of piezoelectric impedance-based health monitoring and path forward.

Park, G., Farrar, C. R., Rutherford, A. C., & Robertson, A. N. (2006). Piezoelectric active sensor self-diagnostics using electrical admittance measurements. *Journal of Vibration and Acoustics*, *128*(4), 469-476.

Peairs, D.M,Park,G,& Inman,D.J (2004). Improving accessibility of the impedance-based structural health monitoring method. *Journal of Intelligent Material Systems and Structures*. *15(2),*129-139

Shin, S. W., & Oh, T. K. (2009). Application of electro-mechanical impedance sensing technique for online monitoring of strength development in concrete using smart PZT patches. *Journal of Construction and Building Materials*, *23*(2), 1185-1188.

Shin, S. W., Yun, C. B., Popovics, J. S., & Kim, J. H. (2007). Improved Rayleigh wave velocity measurement for nondestructive early-age concrete monitoring. *Research in Nondestructive Evaluation*, *18*(1), 45-68.

Tawie, R., & Lee, H. K. (2010). Monitoring the strength development in concrete by EMI sensing technique. *Construction and Building Materials*, *24*(9), 1746-1753.