13th International Conference on
Structural Health Monitoring of Intelligent Infrastructure
DOI: 10.3217/978-3-99161-057-1-086

External Magnetization based Elasto-Magnetic Sensing Technique for Tension Monitoring of Aged PSC Structures

Junkyeong Kim[1]
[1]Research Center for Disaster & Safety, Advansed Institute of Convergence Technology, Gwanggyoro 145, 16229 Suwon, Korea, Republic of
email: junkyeong@snu.ac.kr

ABSTRACT: This study proposes a novel non-contact electromagnetic (EM) sensing system tailored to detect magnetic flux density changes associated with prestressed tendons embedded in concrete structures. The research emphasizes the optimization of sensor head geometry and coil configurations, including single, multi-solenoid, and Halbach array arrangements, to enhance external magnetic field detection at distances representative of real structural applications. Analytical formulations based on closed-form magnetic field equations were validated through finite element analysis (FEA) using ANSYS Maxwell. Results confirm that concentric Halbach-arrayed multi-solenoids outperform conventional configurations in delivering high-density magnetic fields beyond structural surfaces, particularly at target distances up to 30 cm. The verified modeling framework supports further development toward practical integration into structural health monitoring (SHM) systems.

KEY WORDS: External Magnetization; Tensile Force Estimation; Magnetic Sensor; Simulation;

1 INTRODUCTION

The long-term structural integrity of prestressed concrete (PSC) systems relies heavily on the performance and health of internal tendons, which bear the majority of tensile stresses in such structures. Over time, factors such as corrosion, overloading, or construction defects can compromise the tendon condition, potentially leading to severe degradation or even catastrophic failure of bridges, buildings, or other critical infrastructure. Accurate and efficient detection of tendon degradation is thus essential for ensuring public safety, extending structural service life, and reducing maintenance costs.

Conventional non-destructive testing (NDT) methods—such as ground-penetrating radar, ultrasonic testing, and magnetic flux leakage (MFL)—have shown limitations in terms of resolution, access requirements, or signal penetration through dense concrete media. Many existing approaches require contact or partial exposure of the internal tendon system, making them invasive, time-consuming, and impractical for routine inspection in large-scale infrastructure. In particular, methods that rely on internal access or cutting into protective sheaths can inadvertently introduce new vulnerabilities into the structure or disrupt service operations [1][2].

To overcome these limitations, recent research has shifted toward the development of non-contact electromagnetic (EM) sensing technologies capable of detecting magnetic field variations induced by internal steel tendons through external measurements. These techniques leverage the principle that magnetization induced in ferromagnetic tendons (such as carbon steel wires) generates measurable magnetic flux that extends beyond the concrete surface. However, accurately detecting and analyzing such flux from the outside remains challenging, especially at distances exceeding several centimeters from the embedded tendon.

This study proposes a new design and modeling approach for an external, non-contact EM sensor system specifically engineered to detect magnetic flux leakage fields generated by prestressed tendons embedded in concrete. Central to this investigation is the optimization of the sensor head geometry, solenoid coil configuration, and magnetization arrangement to maximize field sensitivity and directional control. Theoretical modeling is performed using closed-form solutions based on vector potentials and elliptic integrals, while simulation validation is conducted through finite element analysis (FEA) using ANSYS Maxwell [3].

2 DERIVATION OF EXTERNAL MAGNETIC FIELD FOR NON-CONTACT EM SENSOR DESIGN FOR EXTERNAL SECTIONS

2.1 External Magnetization Trends by Sensor Head Geometry

Sensor head designs with varying top diameters (0.3 mm to 50 mm) were modeled in ANSYS Maxwell. The diameter of the upper surface was changed from 0.3 to 50 mm and finite element analysis was performed using ANSYS Maxwell software.

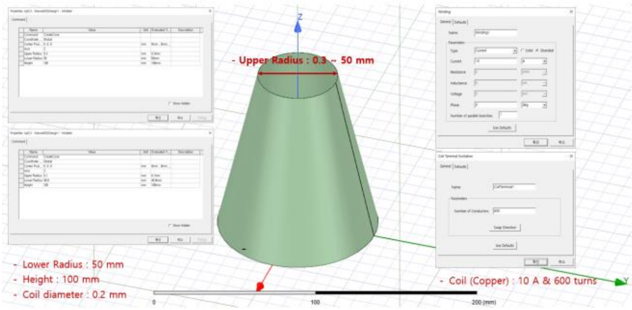
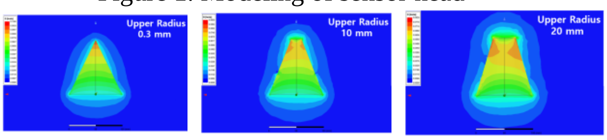


Figure 1. Modeling of sensor head



DOI: 10.3217/978-3-99161-057-1-086

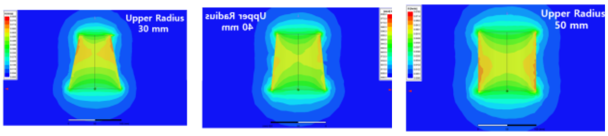


Figure 2. Magnetization according to the shape of head

As the upper radius of the cylindrical sensor increases, the magnetic field concentration effect at the upper part decreases, but the magnetic field dispersion effect into the external space increases.

A finite element analysis was performed on the space of 300 mm above and below the sensor head, and a graph of external magnetization by distance was obtained.

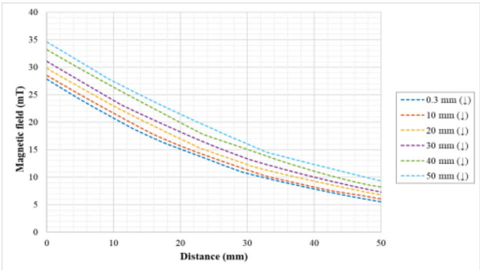
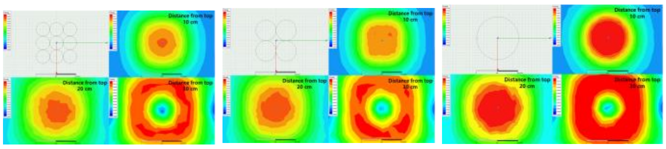


Figure 3. External magnetization according to distance by sensor head type

2.2 *Generating an external magnetic field using multiple solenoids*

The magnetization trend at heights of 10 cm, 20 cm, and 30 cm outside the solenoid was analyzed by changing the diameter of the solenoid (100 mm, 150 mm, and 300 mm) in the same area along the x-axis and y-axis.



(a) 100mm (b) 150mm (c) 300mm

Figure 4. Magnetization degree at heights of 10 cm, 20 cm, and 30 cm for each solenoid diameter

In order to determine the optimal solenoid arrangement with the strongest magnetic flux density in the same area, various coil arrangements were analyzed. As a result, it was confirmed that the arrangement of three concentric circles showed the strongest magnetic flux density at a position of 30 cm.

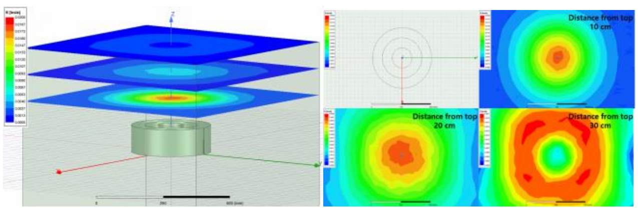


Figure 5. Magnetization degree at heights of 10 cm, 20 cm, and 30 cm for a solenoid arrangement with concentric circles

3 CONCLUSION

This study presented a comprehensive approach for designing, modeling, and validating a non-contact electromagnetic (EM) sensor system for external magnetic field detection, aimed at assessing the integrity of prestressed tendons embedded in concrete structures. Through the combination of theoretical modeling and finite element analysis (FEA), the work systematically explored the influence of sensor head geometry, solenoid arrangement, and coil dimensions on the resulting external magnetization performance.

In the early stages, parametric simulations were conducted to evaluate how varying the sensor head's upper surface diameter affects magnetic field distribution. The results revealed a trade-off between field concentration at the sensor surface and its dispersion into external space, and consequently, a cylindrical head with identical top and bottom diameters was selected as the optimal geometry for external flux detection.

Further investigation into solenoid coil diameter demonstrated that larger diameters yield significantly higher external flux densities. In particular, concentric arrangements of solenoids with increasing diameters (100 mm, 200 mm, and 300 mm) achieved approximately double the magnetization at a 30 cm height compared to a single solenoid of equivalent maximum diameter. These results support the use of concentric, multi-sized solenoid configurations for enhanced long-range sensing.

Overall, the study has successfully established a robust design methodology for non-contact EM sensing tailored to the constraints of structural health monitoring in concrete infrastructures. The integration of analytical theory with numerical simulation provides a solid foundation for practical implementation. Future work will focus on experimental prototyping, performance evaluation in real structural environments, and integration with data acquisition and diagnostic systems to enable autonomous, continuous health monitoring of critical infrastructure components.

ACKNOWLEDGMENTS

This work was supported by a grant (RS-2024-00402840) funded by the Ministry of Interior and Safety (MOIS, Korea).

REFERENCES

[1] J. Simpson and E. Weiner, Eds., The Oxford English dictionary, Clarendon Press, Oxford, UK, second edition, 1989. D. C. Jiles and D. L. Atherton, Theory of ferromagnetic hysteresis, *Journal of Magnetism and Magnetic Materials*, 61(1-2), 48–60, 1986.

[2] H. Zijlstra, Experimental Methods in Magnetism. North-Holland Publishing Company, 1967.

[3] J. C. Mallinson, One-sided fluxes—a magnetic curiosity?, IEEE Transactions on Magnetics, 9(4), 678–682, 1973.