A Novel Wireless Metamaterial-Inspired Rotation Sensor

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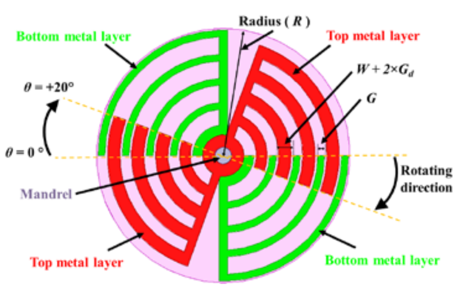
Steel construction structures have been gaining popularity due to the speed and ease of their construction. However, the load-carrying elements in these structures (such as beams) exhibit a bending movement, which is in the form of a displacement along the load axis and in the form of rotation perpendicular to the load axis, in the elastic region. If the amount of rotation can be measured accurately, many critical information from the structural health monitoring (SHM) point of view can be acquired (such as force, stress, displacement, etc.). However, in the elastic region the bending based rotation occurs at very small angles (in the orders of 10^{-4} - 10^{-5} radians), which requires a highly sensitive system that will provide a high resolution. Currently, a wireless and passive technology that can measure the bending on such load-carrying elements with a very high resolution and sensitivity has not been shown in the literature**.** Majority of the available studies are active and/or wired. Furthermore, the focus on these studies is the dynamic range rather than the sensitivity and the resolution. Therefore, in this study, we propose a novel metamaterial-inspired wireless rotation sensor as well as to develop a passive rotation sensing system for the measurement of very small elastic-region bending in materials such as steel. Besides, the system is expected to measure the rotation in other elastic materials, plastic, composites, etc.

The proposed sensing system consists of two elements; an antenna and a metamaterial-inspired rotation sensor whose top, bottom layers as well as the cross-sectional view are illustrated in Fig. 1. The sensor is composed of two dielectric substrates (bottom dielectric and top dielectric) with two planar inter-digital metal layers between them. As shown in the figure, the top and bottom layers are electrically connected to each other with a metallic mandrel. In order to minimize possible frictions, the gap G_a is filled with grease. All the geometrical parameters depicted in Fig. 1 are optimized to achieve the best sensitivity and resolution.

The proposed sensing system operates based on the principle of near-field coupling between the antenna and sensor so that the key features of the sensor such as sensitivity, resolution and signal-to-noise ratio can be improved by the localization and reflection of the illuminated electrical and magnetic fields over it. Briefly, rotation of one of the layers with respect to the other modifies the equivalent LC of the circuit that leads to a shift in the resonance frequency of the structure. This frequency change is recorded from the shift of the resonance dips in the S_{11} response of the antenna. Different types of experiments are performed in order to understand the characteristics of the proposed sensor and the sensing system. During these experiments the main focus is on sensitivity, the monitoring distance, which is defined as the distance between the antenna and the rotation sensor, and the resolution. The validity of the measurement results is verified by using full-wave electromagnetics simulator as well as applying digital image correlation (DIC) method for 2D measurements. Experimental results on these aforementioned features of the sensing system (as well as on some others) will be provided during the presentation.



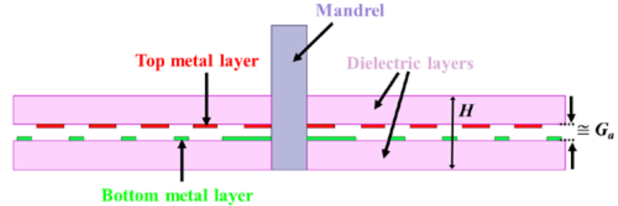


Fig.1 Top and bottom layers and the cross-sectional views of the proposed rotation sensor