Surface Roughness Effect On Eddy Current Probe Response

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Abstract

Modern industrial systems rely on eddy current sensors for critical applications, including non-destructive testing for flaw detection, displacement measurement for machinery condition monitoring, material characterization for quality control and surface inspection. However, a fundamental challenge affects most if not all eddy current applications across diverse domains. Surface roughness influences sensor response and potentially compromises measurement accuracy regardless of the specific application. Although previous studies had identified the significant effect of surface roughness, isolating and quantifying its specific impact remained challenging. This research utilized COMSOL Multiphysics to investigate the electromagnetic field interactions between eddy current probes and various surface roughness profiles. Magnetic and Electric Field physics under the AC/DC module in the frequency domain was used to simulate the interaction. The simulations were conducted in 2-D axisymmetric space. Surface roughness profiles from 0.73 to 16.66 µm Ra were involved. Air-cored absolute eddy current sensors were modeled across excitation frequencies from 10 kHz to 10 MHz using copper test specimens to eliminate ferromagnetic effects. Strong linear relationship was found between surface roughness parameters and sensor impedance response simulations. A quantitative analysis showed that 1 µm increase in Ra produces an equivalent lift-off error up to 2.2 µm. Experimental validation using impedance analyzer achieved 80 percent accuracy. The findings provide the quantitative basis for understanding the surface roughness effect on eddy current sensor measurements. Future work will include analytical calculation of surface roughness effect on eddy current probe response and extension to ferromagnetic material in 3-D space dimension.

Figures used in the abstract

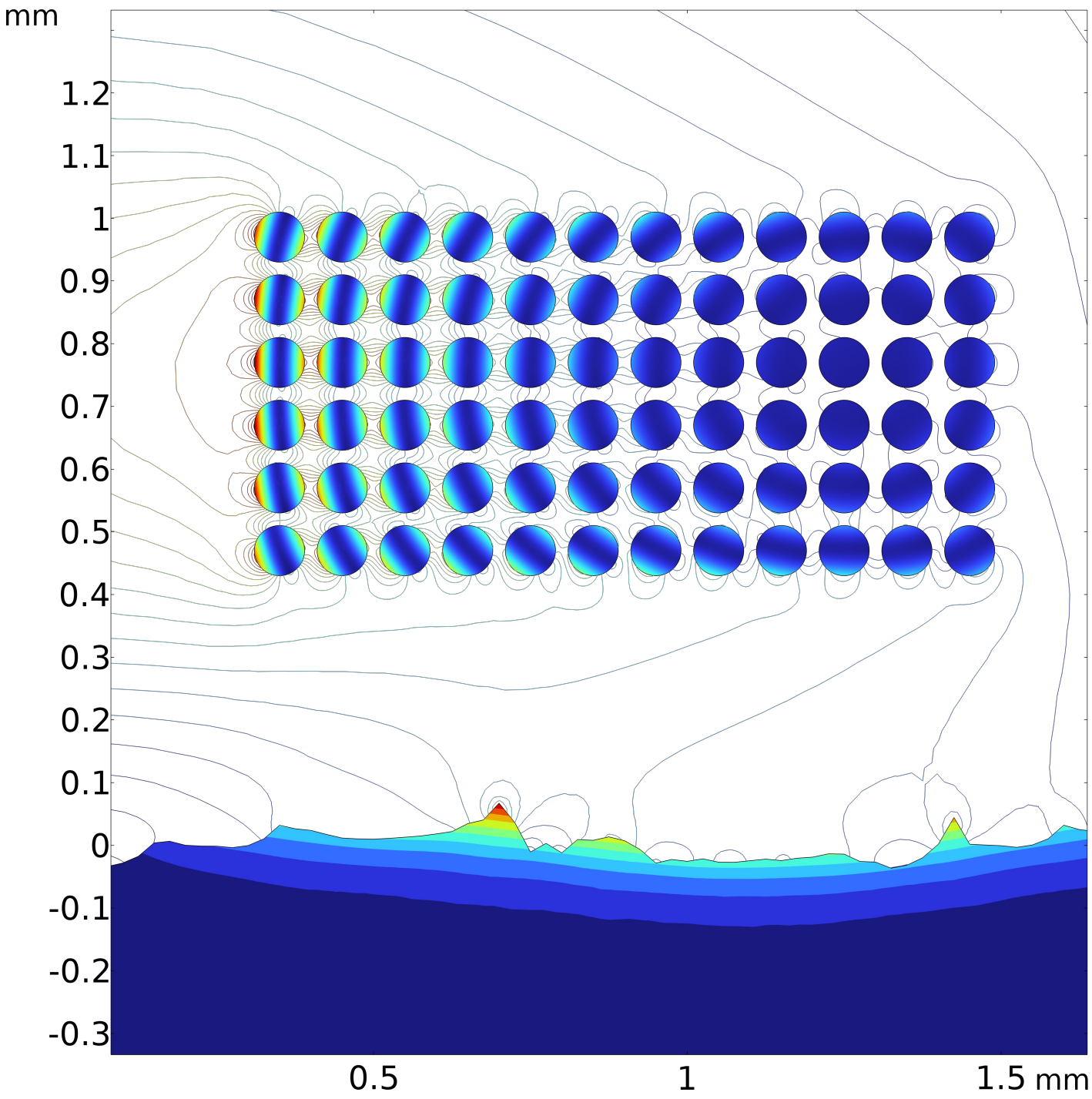

Figure 1 : Current density in the coil conductors and rough surface 4.62 µm Rq.

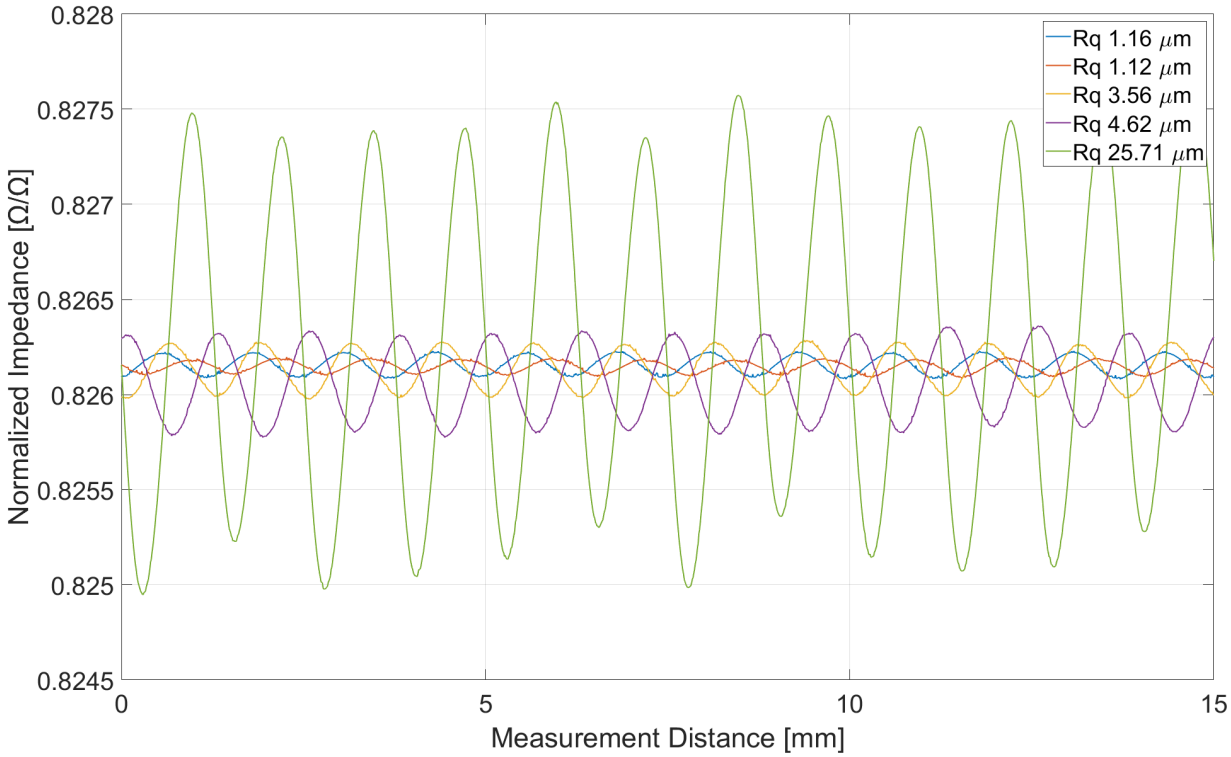

Figure 2 : Simulation of eddy current sensor scan on various rough profiles

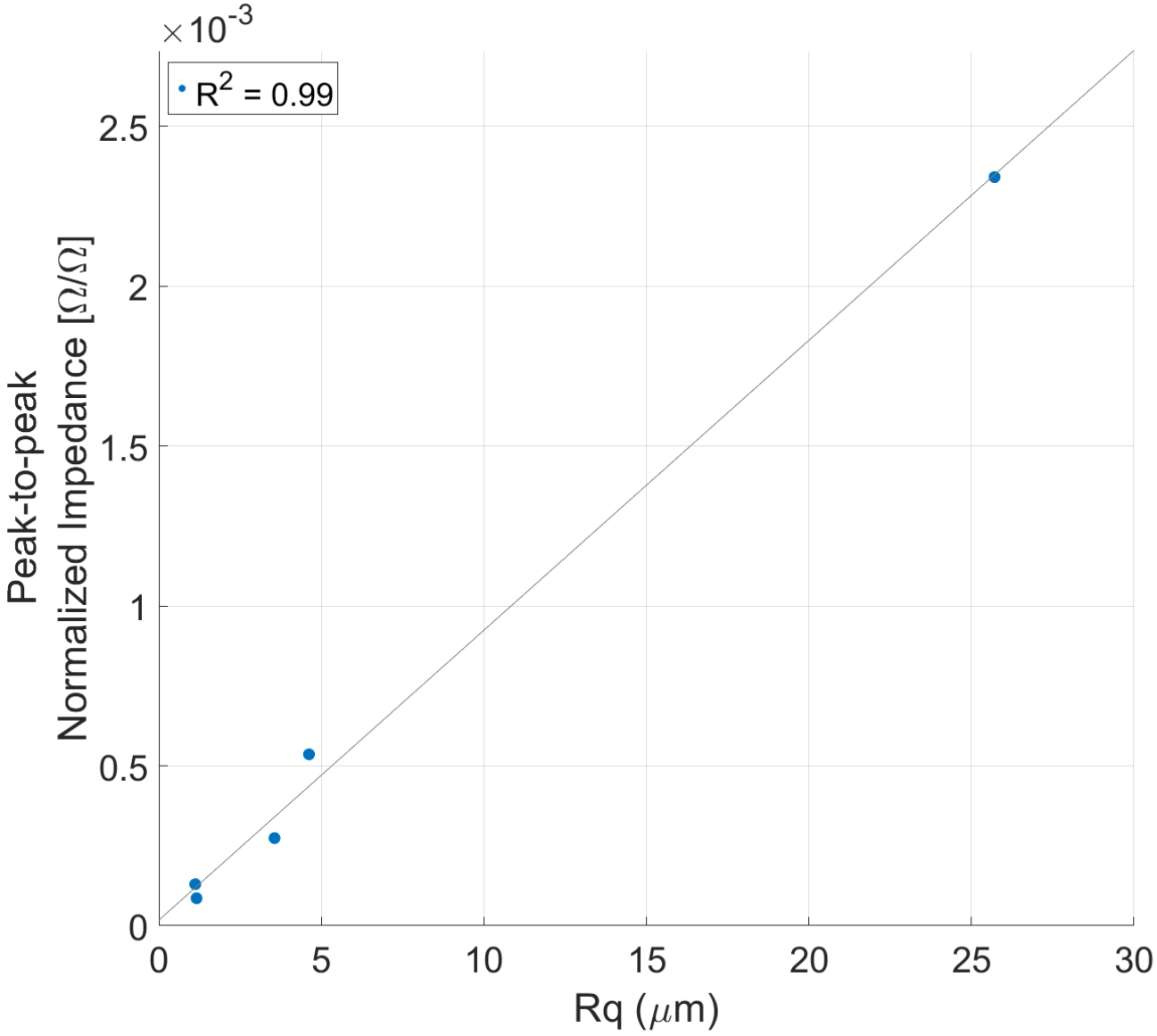

Figure 3 : Linearity study of Rq values and peak-to-peak impedance response of the coil in simulation

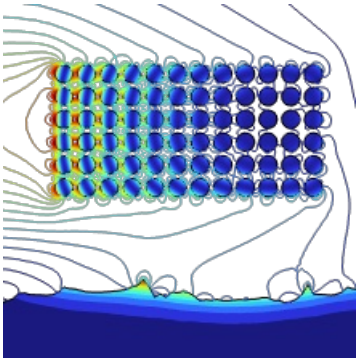

Figure 4 : Thumbnail - Effect of surface roughness on eddy current probe response