Simulation of a Capacitive Sensor for Wear Metal Analysis of Industrial Oils

P. Venkateswaran[1], Rupa Minasamudram[1], Prateek Agrawal[2]

[1]Siemens Technology and Services Pvt. Ltd, Bangalore, Karnataka, India
[2]Indian Institute of Technology - Bombay, Mumbai, Maharashtra, India

Abstract

Lubricant oil is a key component used in industries in order to ensure proper functioning of industrial machinery such as turbines, gears, bearings and compressors. The condition of the oil deteriorates over time due to machine operation, and needs to be monitored frequently so as to prevent structural damage to the machinery. Oil analysis is a diagnostic tool used to detect and quantify presence of wear metals and other contaminants in the lubricant of oil wetted systems. Just as a blood sample analysis reveals details of the physiological well-being of an individual, the analysis of a lubricant sample provides important information on the health of the machine. It is a test that helps to determine whether a mechanical system is in a normal or abnormal wear mode.

A number of techniques for wear metal analysis like atomic absorption spectroscopy (AAS), atomic/optical emission spectroscopy (AES/OES), mass spectrometry (MS), X-ray fluorescence spectroscopy (XRF), ferrography, magnetic chip detectors and Hall effect sensors are prevalent. However these techniques are expensive, time consuming, requires skilled labor and sample preparation. Accordingly, the goal of this work is to conduct a feasibility study on application of capacitive sensing principle for detecting abnormal wear conditions in industrial lubes.

The detection principle is based on sensing the change in relative permittivity of oil as the wear metals pass through the capacitor electrodes. Three configurations of capacitor electrodes, namely, parallel plate, interdigitated (Fig.1) and meandering electrodes (Fig.2) have been studied using COMSOL Multiphysics®. The electrostatics formulation in the AC/DC Module of COMSOL was used to evaluate the sensitivity, defined as change in capacitance per wear particle. The model assumes that the wear particles are spherical in nature, the capacitors are completely immersed in oil medium, and that the fluid is in steady state.

Firstly, the effect of wear particle size and position with respect to electrodes on the change in capacitance of a parallel plate sensor is studied. Next, a model of a planar Interdigitated (IDT) structure on FR4 substrate is created. The validity of the model is established after corroboration of the results with those available in literature. Next, the meandering configuration is modeled. Finally, a comparative study of the change in capacitance for all the three configurations with presence of wear particles is made. The number, distribution, size and shape of wear particles

and all other factors are kept identical for all the configurations. In this case, the number of wear particles is restricted to 12 due to limitation of computational resources.

Simulation results indicate that in all three designs, the change in capacitance increases with increase in particle diameter and the number of particles. Thus the change in capacitance is directly indicative of the wear particle concentration. For 12 wear particles, uniformly distributed, the change in capacitance is around 95fF for the parallel plate capacitor, 200fF for an interdigitated capacitor and 300fF for a meandering capacitor. Thus, the meandering capacitor configuration is the most sensitive (factor of 3 times that of parallel plate) to wear metal detection.

Figures used in the abstract

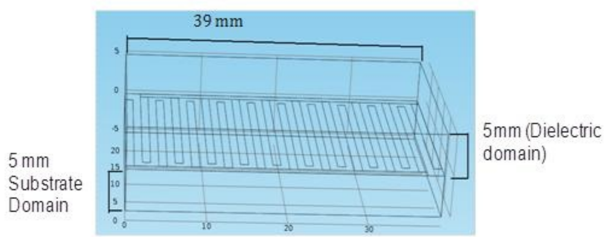

Fig 1: Geometry of Interdigitated Capacitor

Figure 1

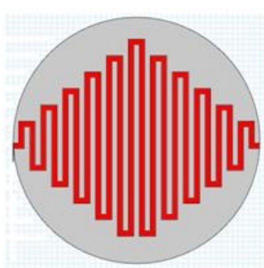

Fig 2: Geometry of meandering electrode capacitor

Figure 2

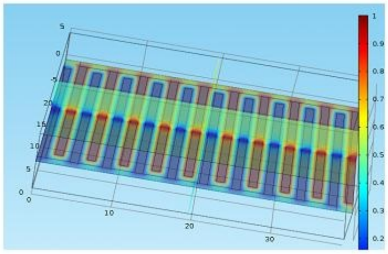
Fig 3: Potential distribution across an interdigitated capacitor

Figure 3