Real-Time Prediction of Incipient Failure in Working Fluids

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Abstract:

Working fluids (engine oil, transmission fluid, hydraulic fluid, coolants, etc.) become contaminated in use. To ensure that the equipment is not damaged by the contaminated fluid, the fluid is typically removed and replaced periodically. For large groups of machines, the used fluid is then shipped to an analysis laboratory and a complicated analysis is performed to ensure that the fluid replacement period is correct for each machine and that each machine is not in need of immediate repair. This procedure is costly, time consuming, and does not always work in a timely manner to prevent machine failure.

This paper presents a new approach to working fluid analysis. The model presented herein demonstrates the value of real-time analysis of the differential electrical admittance of the working fluid in-situ to detect the incipient failure of the working fluid. Once the incipient failure has been detected, the contaminated working fluid can be removed and replaced with new, high quality working fluid, before the machine is damaged.

The model presented in this paper employs COMSOL Multiphysics® and the AC/DC Module. This model is derived from the *Frequency Domain Modeling of a Capacitor* model (12693). In this case, the model is developed to show how the differential electrical admittance changes in the Frequency Domain, as a function of the shift in the parametric value of the electrical conductivity and/or the relative permittivity.

Keywords:

Real-time Prediction, Incipient Failure, Working Fluids

Theory:

In this paper, working fluids are defined as the fluidic materials that are employed as lubricants, coolants, and pressure transfer agents in various mechanical systems. Typically, over time and after use in common applications, such working fluids will inevitability fail to be able perform their design parameter function correctly. The failure of such fluids to perform, typically occurs after some period of time (lifetime), due to both mechanical and thermal cycling of the fluid and due to the inadvertent introduction of contamination (metal particles, carbon particles, water, other fluids, etc.). Arriving at the functional life failure point (end of life, functional lifetime) of the fluid, in situ, may also result in a catastrophic failure for the machine and the mission in which it is a critical functioning component (e.g. trucks, planes, military vehicles and weapons, submarines, etc.). In many working fluid applications, it is presently standard practice that the in-machine working fluids are to be removed and replaced (oil change, transmission fluid, etc.) with new fluids before any such catastrophic event can occur. This practice is minimally adequate, but both excessively costly and time consuming.

On the other hand, the use of a real-time prediction methodology for the detection of the incipient failure of each working fluid, in situ, will allow each fluid to be used in a particular machine for an optimum period of time in that machine. The particular fluid will then to be replaced, at a convenient time, with new fluid before reaching the catastrophic failure point in that machine.

The real-time prediction of incipient failure inherently compensates for the variability of both new fluids and the variability of the incipient fluid failure mechanisms from machine to machine.

In the model presented herein, the real-time prediction of incipient failure is both machine and fluid independent. The incipient failure point (range) is determined by the electrical characterization of an inherent physical property (electrical admittance {1,2}) of the working fluid in question.

Governing Equations:

In this model, the terms herein utilized refer to the analysis of the characteristic electrical properties of the working fluids and how those properties change (become modified) as the fluid ages (is used in situ over time).

1. $Y = 1/Z$

Where: Y is the admittance, measured in siemens
Z is the impedance, measured in ohms

2. $Z = R + jX$

Where: R is the resistance (real part), measured in ohms
X is the reactance (imaginary part), measured in ohms
j is the square root of minus one (-1)

The impedance of a working fluid is determined by the combined properties of the basic fluid and those of the added contaminants. When the impedance of the composite material is measured as a function of applied frequency, the added contaminants cause the resulting curve to be different from the curve measured for the original, pure working fluid. The extent of the difference between the two measured curves can be used to predict the proximity of incipient failure.

COMSOL Multiphysics Model:

This Real-Time Prediction of Incipient Failure in Working Fluids Model is derived from the COMSOL Multiphysics Model #12693. This model employs the **AC/DC > Electric Fields and Currents > Electric Currents (ec)** submodule. The Study chosen is **General Studies > Frequency Domain**.

The geometry chosen is that of a four (4) part capacitor, with a dielectric material (engine oil) located between the two (2) horizontal plates. See Figure 1.

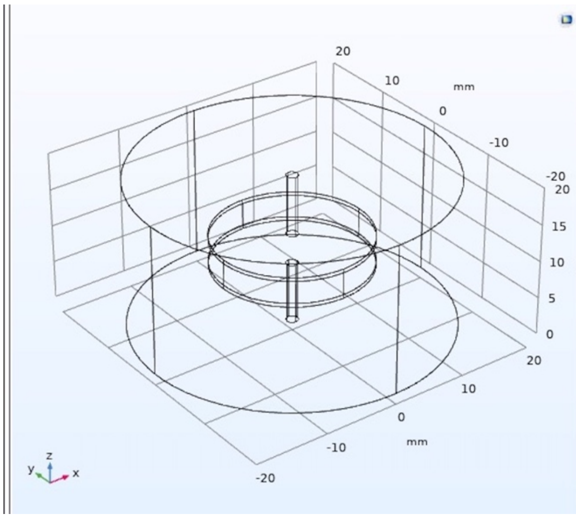

Figure 1 Capacitor Structure

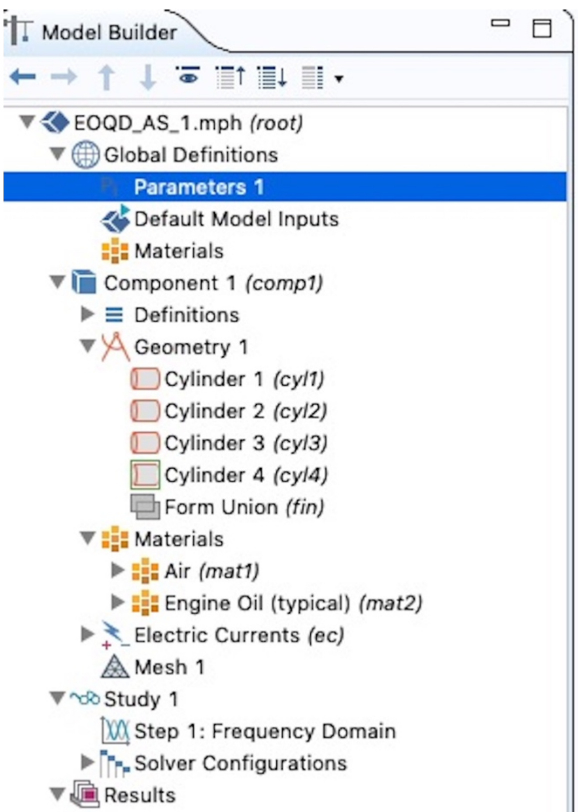

Figure 2 Model Builder Model Details

Figure 2 shows the capacitor build and material specification details.

Figure 3 shows the parametric variables that were added to the original model to allow for the electrical property changes caused by the contamination of the engine oil.

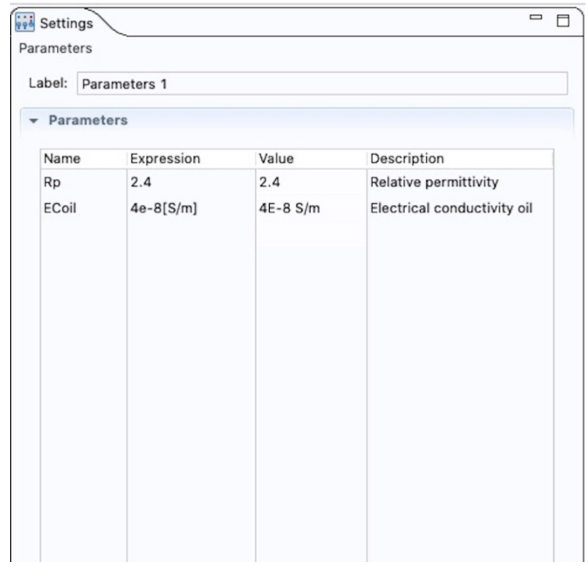

Figure 3 Engine Oil Parametric Values

COMSOL Multiphysics Model Computational Results:

In order to display the calculated results, a 1D Plot Group was added, as can be seen in Figure 4.

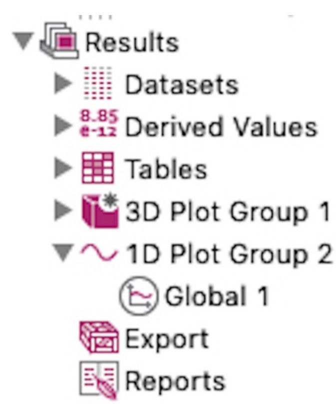

Figure 4 Model Builder 1D Plot Group

Calculated Results Graphs:

Figure 5 shows the admittance values vs frequency for pure engine oil.

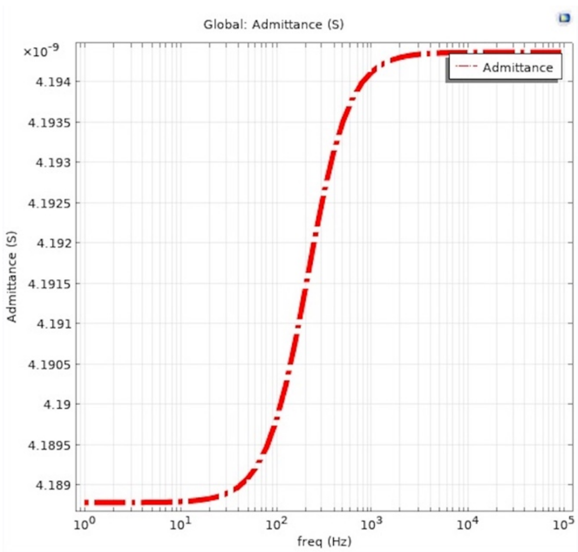

Figure 5 Engine Oil (Pure) Admittance vs Frequency

Figure 6 shows how the shape and location of the admittance vs frequency curve changes after a small amount of water is added as contamination to the engine oil.

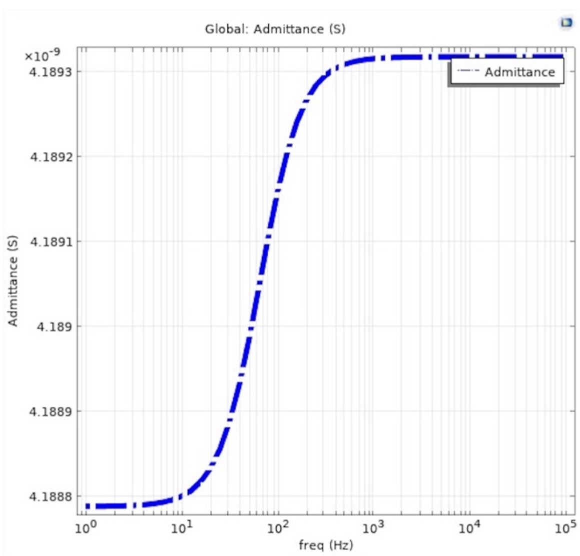

Figure 6 Engine Oil (+H2O) Admittance vs Frequency

Figure 7 shows how the shape and location of the admittance vs frequency curve changes after a small amount of water and metal or carbon particles are added as contamination to the original engine oil.

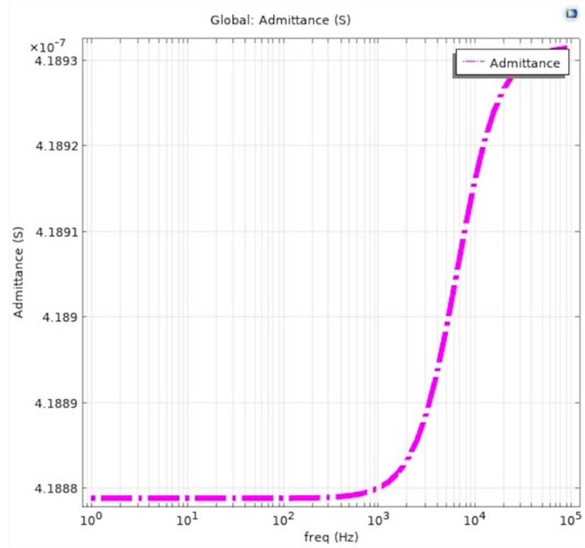

Figure 7 Engine Oil (+H2O + Particles) Admittance vs Frequency

Conclusions:

The use of a real-time prediction methodology for the detection of the incipient failure of each working fluid, in situ, will allow each fluid to be used in a particular machine for an optimum period of time in that machine. The particular fluid will then be replaced, at a convenient time, with new fluid before reaching the catastrophic failure point in that machine.

References:

1. https://en.wikipedia.org/wiki/Admittance
2. https://en.wikipedia.org/wiki/Electrical_impedance