SAFETY AND TRANSPORT
ELECTRONICS

WP2 SAMPO
– Online condition monitoring techniques - Dielectric Properties

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Content

Background

Changes in the chemical structure and overall composition of the materials are likely to affect the dielectric properties and there are previous examples where changes in dielectric properties have been linked to aging of polymeric materials (Daily, 2015; Li, 2011). The effects of ageing on the dielectric behaviour of the materials in question could be measured using e.g. impedance/dielectric spectroscopy. A very convenient method to monitor the status of rubber or polymer materials would be to measure material changes online. If there are large enough changes in dielectric behavior of the materials that can be directly related to the ageing process, it should be possible to follow these changes using antenna dielectric sensors (Huang, 2015). By mapping the dielectric behavior of the materials under test, antennas could hopefully be designed to fit the frequency providing the highest sensitivity. Placement, environmental factors and calibration of sensors would likely also be issues necessary to address as well as monitoring moisture and temperature to avoid overlapping effects of moist content and degradation of the monitored polymers. This strategy towards assessment of polymer ageing has been part of Task T2.1 - Online condition monitoring techniques in the SAMPO project.

Goal of the study

The goal of this study was to assess the available techniques, for dielectric characterization of polymer materials, that might be suitable or adaptable to measurements over a large timespan where there is no direct access to the material under test after installation on site.

Methods

During these initial stages this task has been entirely approached as a literature study. Focus has initially been towards very general information on dielectric characterization and antenna sensors with some extra effort put towards techniques, used in other industries, for monitoring dielectric changes. From this, efforts have been made towards suggesting some technique that could be evaluated for feasibility together with some form of accelerated ageing.

Results and discussion

Dielectric characterization

Dielectric characterization means an investigation into the polarization behaviour of a material when it is exposed to an electromagnetic field (Deshmukh et al., 2017). What is referred to as the dielectric constant is the same thing as the real part of the complex permittivity. In many cases the entire complex permittivity may be of interest as e.g. transitions between different dominating polarization mechanisms may be easier to detect if looking at e.g. the imaginary part of the permittivity.

There are many ways to characterize the permittivity of a material (Huber et al., 2018; Jiang et al., 2000; Liu et al., 2018; Rydholm, 2015; Venkatesh and Raghavan, 2005) but many of them demand specific set-ups which appear to show poor compatibility with online monitoring of materials over a long time span in complex environments and are thus better adapted to characterization in a laboratory environment. Many of these techniques do however have the advantage of possibly spanning a larger frequency regime. They might thus still be of interest when searching for suitable frequencies at which more narrowband sensors could in turn be used for monitoring. In the following sections some systems that could be interesting for online monitoring of permittivity are briefly described.

Antenna Sensors

The passive, wireless operation of antenna sensors makes them an attractive candidate for applications in which the sensor could be physically inaccessible for long periods. Passive in this context means that they normally do not need any on board battery to function (Huang, 2015). Early types of antenna sensors include inductively coupled sensors and Surface Acoustic Wave (SAW)-based sensors. Inductively coupled sensors demand a reader antenna which is placed in the near field of the antenna sensors. This means the interrogation distance will be quite small. SAW-sensors typically operate at fairly low frequencies (< 100 MHz) which could make them unsuitable if the investigated material changes e.g. are only detectable at higher frequencies. Another disadvantage of working at low frequencies is that miniaturization of the sensors become more difficult due to the longer wave lengths. More recent passive wireless sensors are RFID and antenna sensors. RFID sensors have traditionally had some form of chip in their circuitry that harvests the energy of the interrogating signal, which can then be used to transmit information back. The chip can typically also hold some data memory which can be transmitted. Some RFID sensors also hold some form of other intelligence that may be involved in sensing and simple calculations. What can be referred to simply as antenna sensors normally hold a much simpler configuration consisting only of an antenna and some form of modulator. The antenna can be any kind of normal antenna and the modulator simply modulates the interrogation signal so that the backscattered signal can be separated from the background. The sensing can be performed by detecting changes in the radiation characteristics of the antenna. If the antenna e.g. is covered in a material which undergoes a permittivity change with degradation, that degradation should be visible as a shift in the resonance frequency of the antenna.

Applications in Other Fields

Because of the scope of this project we have tried to look specifically for antenna sensors sensing permittivity or material degradation in some form, either for the direct interest in that property/process or as an indicator for sensing something related to it. Inductive sensors have been used e.g. for environmental monitoring (Ong et al., 2001), bacterial growth (Ong et al., 2002) and biopolymer degradation (Salpavaara et al., 2017, 2016). Work has also been reported on corrosion monitoring using antenna sensors (Zarifi et al., 2017; Zhao et al., 2017). Often permittivity itself can be found as a property of interest to measure (Girbau et al., 2012; Saghlatoon et al., 2019, 2018).

One noteworthy application was the use of antenna sensors for radiation detection in NPPs through ferrites and ferroelectric materials (McCloy et al., 2009).

Chipless RFID

Chipless RFID is a technology that bears much resemblance with some materials permittivity antenna sensors. It appears to be a fairly new concept and is mainly proposed for encoding non-sensitive information readily available for simple read out (Abdulkawi et al., 2019; Issa et al., 2018; Nair et al., 2014, 2014; Sajitha et al., 2016). A simple analogy to the normally proposed application would be a bar code or QR-code, but the chipless RFID tag would not need to be optically visible. The encoding is done by designing electrically resonant structures which can thus reflect incoming electromagnetic waves at specific frequencies. As the resonances depend on the permittivity of the surrounding material this could be used as a simple sensor at specifically designed frequencies of interest which would correspond to what could be referred to as "encoding" of the sensor (Nair et al., 2014). This approach has the advantage over many other antenna type sensors of not needing to contain any other circuitry than the conductors and the material under test. This should enable very robust sensors.

Cable Impedance Measurements

At this time not much effort has been put, within this project, specifically towards cable measurements as very little information on exact cables, connection possibilities etc. has been found readily available. From discussions with representatives from Swedish nuclear power plants there has however emerged a request for a simplification of the interpretation of the results acquired in the LIRA-method employed today. Furthermore, from discussions at the project seminar in Espoo in November 2019 it became apparent that there might be a renewed interest in permittivity/dielectric or, the closely related property, impedance measurements for cable jackets. The impression given is that effort has previously been towards looking at the real part of the measured entity, while measures related to the imaginary part or entire complex measure may be of greater interest. Reflectometry techniques combining time and frequency domain data was also mentioned. If there is continued interest these are topics that could be further explored. The literature on both frequency and time domain measurements for cable diagnostics is quite extensive, e.g. (Ohki et al., 2011; Rogovin and Lofaro, 2006; Wang et al., 2008; Watson and McDaniel, 2014; Zhou et al., 2015), but there might still be an opportunity to help interpret the results from these methods and adapt them to a more practical use.

Conclusions

From the literature it appears that the dielectric properties could indeed in some cases be related to the ageing of the polymers and should thus be of interest for further study. Simple resonant structures in contact with, or embedded into materials, could be one way of monitoring the degradation possibly compatible with methods for accelerated aging or microcalorimetry. The possibility of designing such a test should be further explored. Furthermore, it could be worthwhile further exploring the cable dielectric measurements in used today and how the data is normally analysed.

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