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Passive resonance sensor based method for monitoring particle suspensions

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ABSTRACT

Control of particle suspensions is needed in several modern industrial processes. A reason for the difficulty in this task has been the lack of a fast and reliable measurement. In this study, we tested the measurement of particle suspension by using a method based on a passive resonance sensor. The relative amounts of dispersing agent and aluminium oxide in the suspension were varied. The studied method yielded signals which depended on the complex permittivity of the suspension. The results indicated that we were able to measure information that can be used as feedback for the suspension preparation process. In addition, the tested instrumentation was simple and robust and thus this method may allow online measurements directly from the industrial processes.

1. Introduction

Monitoring and controlling particle suspensions are essential parts of many modern industrial processes. One example is the manufacturing of technical ceramic components. The use of these components has increased in challenging applications due to their ability to withstand wear, high temperatures and corrosive environments better than traditional materials. These components are often manufactured via processes such as spray drying or slip casting where fine ceramic particles need to be suspended in liquid. The properties of the final components are highly dependent of the properties of the suspension [1]. It is important that the suspension is homogenous. In other words, the particles and additives have to be dispersed evenly in the suspension. Also, the solid content has to be as high as possible and the amounts of additives should be precisely at correct level. Thus, to increase efficiency and yield in processes that use suspensions, it is essential to develop industrially capable methods to characterize them.

Despite the fact that the slurry monitoring is an important part of the ceramic component manufacturing process, the commonly used quality assurance measurements are difficult and time-consuming. Usually a sample is taken and it is characterized in a laboratory. There are also measurement systems that have automatic sampling devices. Typical characterization methods are rheological measurements [2], centrifugal sedimentation tests [3], particle size and size distribution measurements and zeta potential analysis [4]. In addition to the challenges of getting representative samples from huge vessels, the transport to laboratories and the characterization tests take time. Thus, the results cannot be acquired in real time and cannot be used as effective feedback for the process. Hence there is a need for a non-invasive, inexpensive, rapid online-method that monitors qualities such as solid content, sedimentation and the effects of the additives. In addition to the traditional measurements, alternative methods have been developed based on ultrasound [5–7], microwaves [8] and electrical conductivity [9–11].

One other physical property of the materials that can be electrically measured is the relative electrical permittivity. This property describes how the electric field is affected by the dielectric medium compared with vacuum. The relative permittivity is calculated from a capacitance measurement. The typical form of the capacitive measuring element is a coaxial probe [12]. The probes are placed in the measured media and the measuring electronics or an amplifier has to be located in the close proximity of the probes to prevent noise pickup and parasitic capacitances. One other challenge of this method is to understand and control how the geometry of the

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capacitive probe affects the measured results. This can be problematic in industrial environments.

The dielectric or capacitive characterization techniques have been also tested for monitoring suspended particles [13–17]. In [14] Sjöblom et al. measured complex permittivity by using a dielectric sensor. The form of the sensor in these measurements was a capacitive coaxial probe. The dielectric sensor was measured by a computer controlled system that included a pulse generator and an oscilloscope. By using this method, the features like the sedimentation and volume fraction of Al_2O_3 were monitored. Despite the obvious advantages, this method, as such, is not popular in the ceramic industry to the best of our knowledge.

One variant of a dielectical measurement can be done using passive resonance sensors. The concept of passive resonance sensor has been known since the mid of the last century. In short, the principle of the method is to measure the behaviour of an LC circuit by using another coil [18]. When the reader coil is placed near to the LC circuit, an inductive link is formed. Because of this link, the resonance of the LC circuit can be detected when the impedance of the reader coil is measured. Different readout methods have been developed but the measurement of the complex impedance using an impedance analyser is one of the most common in the scientific studies [19–21]. The concept of passive resonance sensors has two notable advantages: it allows a short range wireless measurement and the structure of the actual sensor is very simple. The LC circuit can be measured through non-conductive materials like plastic or glass. However, it should be noted that this method does not allow making measurements through metallic container walls and the errors due the metallic objects in the measurement environment have to be investigated. The range of the measurement is relative to the dimensions of the coils, typically few centimetres. The simplicity of the sensor structure allows the use of nonconventional materials and makes the sensor durable and cheap to manufacture.

The applications of the passive resonance sensors range from simple pressure sensors to the measurement of chemical [20,22] and even biological variables [23]. The wide range of the applications is due to the fact that most of the typical measurement can be converted to the measurement of capacitance, resistance or inductance. All those quantities can be measured by using passive resonance sensors. A typical realization of this concept is a pressure sensor based on a pressure dependent capacitor [18,21,24]. Other tested applications are implantable sensors [18] and the measurement of moisture in sand and concrete [25]. The concept has also been used for measuring biopotential signals [26] and pH-value [20]. A new promising application for this concept is in biodegradable sensors [27,28].

The passive resonance sensors can be used to monitor the permittivity of their environment [19]. In [19] the real and imaginary parts of the complex permittivity have been calculated from the measured data with moderate success. This process requires and is dependent on accurate information of the sensor parameters and the constant that links the geometry of the sensor capacitor and the permittivity of the environment. The measurement of permittivity enables to detect the ratios of components in liquids [19] and gasses [29].

In this study, we investigate the possibilities of passive resonance sensors to monitor the preparation and composition of particle suspension. We selected aluminium oxide slurry as our test material since it is a common and well understood example of particle suspension. The tested slurry contains water, ceramic particles and additives. The proposed method combines the dielectric characterization techniques and a sensitive wireless measurement system. Thus we are able to measure slurry that can be used in a slip casting process without a complicated test arrangement. Also this method does not need excessive or expensive instrumentation and thus it may be transferred to the industrial environment in the future. The first goal of this work is to test if this method can be used to measure the volumetric ratio of ceramic particles dispersed in slurry. Secondly, since the use of dispersing agent is needed, its effects on the measurement are also studied. In this study, we verify the basic functioning of the measurement method.

2. Methods

The tested measurement method is based on the concept of passive resonance sensors. A magnetic field generated by a reader coil induces an electrical current to the sensor coil that creates an electrical field in the capacitor of the resonance circuit. The created electric field also partly passes through the measured substance, in this case slurry. The changes in the permittivity of the slurry will affect the equivalent capacitance of the sensor. In addition, the complex permittivity of the system will cause losses that can be measured.

2.1. Measurement setup

The cross-section of the measurement setup is shown in Fig. 1(a). The LC circuit tested in this work was made of a 7 μm thick etched aluminium pattern which was laminated between two 80 μm thick PET films. This pattern included a rectangular coil with three turns. The width of the coil wire was 0.6 mm. The diameter of the turns ranged from 14 mm to 21 mm. The pattern also had two rectangular 1 cm^2 surfaces which formed a parallel plate capacitor when the laminated film was folded in two and glued together. This structure encapsulates the LC circuit. The structure is durable, thin and easy to make. The capacitance and the resonance frequency of this kind of structure are sensitive to permittivity changes in its close proximity. The circuit was glued to the bottom of a glass container (borosilicate glass, diameter 115 mm, volume 500 ml) and then the sensor was embedded in the container by pouring a thin layer of epoxy on the bottom of the container (Fig. 1(b)). The thickness of the epoxy on top of the sensor was 0.3 mm. This layer was used to limit the effect caused by the measured substance on the resonance circuit. Without this layer, the conductivity of the slurry would cause excessive losses and the resonance of the sensor would be hard to detect. By using this configuration, the measurement

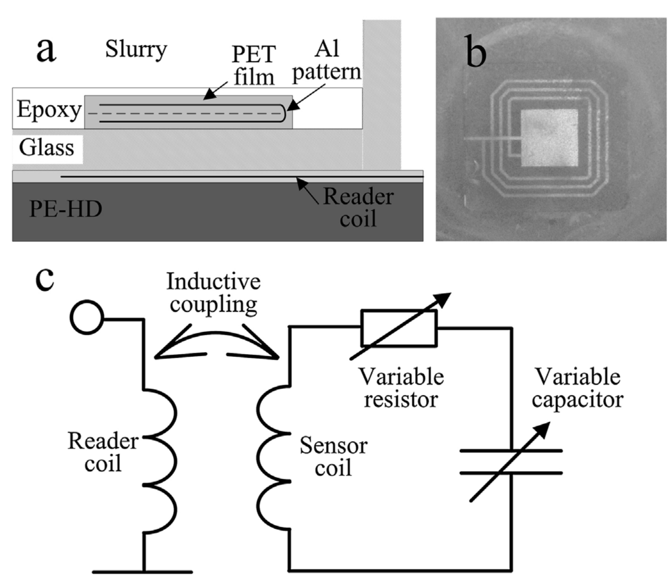

Fig. 1. (a) The cross-section of the encapsulated LC circuit in the measurement container. (b) Picture of the sensor embedded in epoxy. (c) The lumped element model of the measurement setup.