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Non-Contact Electromagnetic Control Methods of the Specific Conductivity Powders Materials, Solid Inorganic and Polymer Film.

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ABSTRACT

Specific conductivity is one of the defining parameters of the powdered materials, solid inorganic and polymer film. These properties can characterize not only physical parameters as it but also materials purity, components uniform distribution, etc.

Test the specific conductivity for materials characterization can be use in chemical industry during materials synthesis. Specific conductivity of materials is especially important also for energy storage industry (battery, supercapacitor, fuel cell) where some electrodes and electrolyte materials with a low conductivity are used.

Well known contact methods for testing the conductivity of powdered materials, solid or polymer plasticized film, (for example battery electrolyte) have several disadvantages connected with the direct contact between the test probe and the material surface. Information about conductivity includes additional resistance between probe and materials surface. This error depends significantly on the contact pressure and area of contact between probe and materials, as well as the operating range of material conductivity and its plasticity in the case polymer film. In a number of cases, (powders or thin films of a few tens of microns) this parameter is practically non -measurable due to the impossibility to attach the electrodes to material.

The goal of current is to develop an effective non-destructive non-contact methods and devices for test conductivity powdered and thin film materials.

Method's background.

It is known a number of devices for non-contact conductivity measurement in conducting materials – metals and their alloys by electromagnetic eddy-current method [1,2]. However, neither a sensor design, nor their operation frequency ranges are unacceptable for work with relatively low-conducting materials. Low conductivity of materials stipulates the work necessary to get the appreciable reacting of sensor to tens and hundreds of MHz. In this case, use of the classic methods becomes problematic due of tuning away from the influence of clearance changes between the sensor end and the material surface based on the phase conversions. It is connected with the increasing amplitude-phase error, parasitic incursions in the channels of phase indicator, etc.

The method sensitivity depends on the frequency of eddy magnetic field of probing material by its specific conductivity

$$Z_{ad}=48\times10^{-7}\omega RW^2e^{-3/2\alpha}\beta^2\varphi(\xi,\beta),$$

where $\omega=2\pi f$ –circular frequency; R- radius of eddy-current sensor; W- a number of turns; $\alpha=2h/R$, where h- value of the clearance between working surface of eddy-current sensor and the surface of the controlled material; $\beta=R\sqrt{\omega\sigma\mu_0}$ – generalized parameter, σ- specific conductivity of material; $\mu_0=4\pi\times10^{-7}$Гн/m; $\xi=2d/R$, where d – thickness of powder (film) layer; $\varphi=(\xi,\beta)$ – special function.

For determination of specific conductivity by non-contact non-destructive control method we have obtained:
- special mathematical dependence conformably to the resonance method, allowing to calculate specific conductivity by the indirect measured parameters.
- special designs of applied and straight through parametric converters have been developed.

This method enables tuning out from the influence of the change of clearance and skewing of eddy-current converters relative to the surface of the measured object. Modulus of the specialized microprocessor with the analogue channel of data input is the core of the apparatus solution of the method.

Conductivity test powdered material.

Common contact measurements of the powdered materials conductivity, in the main give the information about the value of contact resistance between grains. Their results depend significantly on the powdered material density, electrical properties of powder grain surface and are characterized by the essential errors running up to 20-30% and more. This error depends significantly on the amount of grains contacting with the area of measuring electrode at each measurement The contact measurements fail to determine powdered materials conductivity as the electrical resistance of the grains chain to the current that flows in succession through them is mainly determined by the contact resistances in places the grains contact each other, while these resistances substantially exceed their inner resistances.

This is explained by two reasons. First, the contacting grains, when the powder is of minor density (within the operating range of the powder densities being used for electrode coats of the chemical power sources) obtained by vibration compacting, have relatively small areas of contact there among. Second, the surface resistance of the powder grains is as a rule substantially higher of the volume resistance. This is explained by a lower concentration of free charge carriers on the surface of the grains and by their lower mobility, by forming, due to the chemical interaction with the atmosphere, of various types of insulating films, surface layers, inclusions, etc.

The authors of the paper have developed the main principles of electromagnetic eddy-current method measurement of the conductivity of material grain of non-metal powders and concentration of grains (oxides, sulphides, different modifications of graphite, spinel, etc) at the different bulk densities of powders. Developed method could be transformed from stationary conditions materials test after synthesis to conditions active test during material synthesis.

Conductivity test solid inorganic and polymer plasticized film.

Solid inorganic and polymer solid or plasticized film materiel often use as electrolyte energy storage like lithium battery, supercapacitor, fuel cell. Serviceability of chemical power sources is determined to a great extent by the properties of their solid or polymer electrolytes. Among these properties, ionic conductivity is of particular significance.

For use of the non-contact electromagnetic method for testing conductivity of solid electrolytes several serious problems must be addressed. The surface of the samples is some times quite small making it difficult to use differential measurements. The introduced impedance of the induction coil within the meter wave length range (corresponding to the operating frequency range of the eddy-current conductance measurements of polymer electrolytes) is subject to the influence of the dielectric losses of the polymer. Hence, the conductivity being measured depends on the frequency even in case where the conductivity of the polymer electrolyte is related to the movement of the free charge carriers and is frequency-independent.

Electromagnetic methods with the combined sensor and electromagnetic capacitance methods developed by authors of this paper will allow generation of valid results for the measurement of specific electrical conductivity of solid inorganic or polymer electrolytes. Depending on electrolyte conductivity, it is preferred to use the combined sensor or capacitance non-destructive non-contact method.

In the case electromagnetic methods with combined sensors the measurement is achieved by means of an integral probe for non-contact electrical conductivity determination in polymer electrolytic films. The method consists of placing the film on a flat dielectric substrate, excitation of an eddy-current magnetic field by means of an inductance coil at a series of discrete frequencies, and measuring its impedance at these frequencies while the operating end face of the coil is located on the film surface and on the substrate.

In the case of the non-contact capacitance measurement method of ionic conductivity in solid electrolytes a complex methods based on the use of converters with a harmonically variable electric field is used. Contact areas of the same shape and surface area are applied to the opposite faces of a sample located on the same axis. Measurement of the frequency characteristic of the sample active resistance between the contact electrodes is then carried out, along with investigation of the characteristic frequency gradient for the active resistance of the sample.

Summary

The developed non - contact electromagnetic methods of non-destructive control exclude influence of contact phenomena at determination of the parameter of specific conductivity and provide the possibility of the automation of measurement process and increase accuracy and objectivity of the measurements.

In the presentation, the conductivity investigation results of the different powdered and film materials for example electrolytes and electrode materials promising for lithium chemical power sources and fuel cells will be presented. Special type electrode powdered materials, solid inorganic electrolyte for full solid state battery, polymer electrolyte for lithium battery and fuel cell developed by authors of the paper as well.

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