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A device for measuring conductivity of dispersions

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ABSTRACT

A device to measure pulp electrical conductivity in an industrial environment has been developed. It is based on a variable oscillator circuit whose output period of oscillation is proportional to the sample conductivity. This circuit requires a single point for its calibration, which facilitates its use in an industrial environment. A Nexys2 FPGA (Field Programmable Gate Array) is used to measure the oscillation period, display the data on a LCD screen, communicate the information to a computer by RS-232 and manage the switching of sample probes for multiple measurements. Results have confirmed a linear relationship between frequency and resistance over a wide operational range, between 0.1 mS/cm and 10 mS/cm. Its application in an industrial flotation process in order to estimate froth depth and gas hold-up without prior calibration under certain conditions is also explained and validated.

1. Introduction

Electrical conductivity, an intensive material property, has been used extensively to monitor some important variables of mineral separation processes such as froth depth, gas hold-up and bias rate in flotation systems [1,2] as well as the interface between the clarification-compression zones in thickening [3,4].

Traditional procedures used to estimate electrical conductivity electrifies the probe with an alternating current at a frequency that is high enough to avoid electrolysis and polarization [5]. Circuits measuring conductivity can be categorized in three different groups: (a) those finding equivalent impedance by manipulation of particular circuit components such as variable RC impedances, (b) those finding a relationship between conductivity and voltage drop measured at certain points of the circuit, and (c) those finding a relationship between the period of a signal generated from an oscillator circuit and conductivity.

For the equivalent-impedance methods, different approaches have been studied. Ferrara et al. [6] designed an A.C. bridge to find the complete model, including the cell (RC model). This approach is completely manual and restricted to conductivities under 1 mS/cm. Rehman et al. [7] proposed a system for calculating a sample conductivity by using a four-electrode probe to avoid polarization and D.C. parasite components. This strategy is also based on a bridge balance that is manually adjusted to find the equivalent resistance. Jones [8] aimed at an automated bridge balance to determine impedance similar to that of the sample. Samples are inserted into a cell, and the bridge is balanced automatically every two minutes with a commercial four-terminal pair impedance bridge. Another balance method, proposed by Mercer [9], evaluated the sample resistance using a two-steps tuning of a circuit designed mainly with operational amplifiers. Approaches based on matching conductivity with electrical

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components are usually manual and only valid on a restricted range of conductivity. Their stand-alone operation is complex and requires special components such as automated A.C. bridges.

Methods determining conductivity based on one or more voltage measurements are the most widespread given their high automation possibility. These techniques relate conductivity to some voltage drops in a circuit and the sample conductivity. Some approaches are complex, such as that of Lario-Garcia and Pallas-Areny [10], who proposed a three by three equation system to estimate conductivity. Other approaches result in a nonlinear relationship requiring previous computation such as that of the quadratic relationships [11–13]. The last one also proposed an automated circuit to measure multiple cells probes to estimate a conductivity gradient in a flotation column. This design offers serial communication to a computer to calculate conductivity using nonlinear functions The main disadvantage of this method is the high load produced in the power supply when all cells are connected. Furthermore, the resolution is adjusted by correctly selecting a set of components. Other techniques also include temperature-based conductivity compensation [14,15], leading to more complex functions to estimate conductivity. Da Rocha et al. [16] designed a simplified method in which the electrical conductivity is proportional to a voltage drop in a point of the circuit, requiring a single-point calibration. This method also allows for the selection of the measurement range using a switch to increment the precision for low-conductivity values. They proposed an automated circuit to measure multiple cells probes to estimate a conductivity gradient in a flotation column. This design also offers communication by serial port to estimate conductivity in a computer using nonlinear calculations. The main disadvantage of this method is the high load produced in the power supply when all cells are connected. Furthermore, the resolution is adjusted by a correctly selecting a set of components.

Techniques where conductivity is a function of a voltage measurement are sensitive to noise, and their resolution is restricted to the number of output bits of analog-to-digital converters. This last characteristic limits its stand-alone use when conductivity changes over a wide range of conductivities. In addition, since the relationship between measured voltage and conductivity is usually nonlinear, the resolution is related to the changes in the function slope.

The third category consists of methods wherein the conductivity of the sample is a function of the frequency of a proposed oscillator circuit where the probe is connected. Rosenthal [17] used an oscillator whose output frequency was proportional to the conductivity. Due to the difficulty in measuring the oscillator circuit oscillation period, the output signal of the oscillator was rectified and a relationship between the rectified voltage in the output and the conductivity in the cell was found. Another approach is based on oscillators where the conductivity is a non-linear function of the output frequency. For instance, Hawkins [18] found a square relationship between conductivity and the oscillation frequency in a modified band-pass filter. This circuit is designed to measure conductivities as low as 1000 μS/cm. Another design based on a logic gate oscillator was introduced by Sahoo et al. [19]. The conductivity was found to be proportional to the square of the oscillation frequency. The system design includes communication by serial port and is valid for conductivity ranging from 0 to 1 mS/cm.

Strategies where the frequency is measured to estimate conductivity, minimize the problem of noise and D.C. components. Measurement resolution can also be improved by increasing clock frequency, which is less expensive than increasing the resolution of the analog-to-digital converter. Furthermore, they allow data to be transmitted over long distances with no signal degradation since they handle digital signals.

An electronic device used to measure electric conductivity is presented here. It is based on a variable oscillator circuit where one of its resistances is replaced by the one to be measured, so that it has a linear relationship with the circuit oscillation period. The operating range can be easily adjusted by changing the value of oscillator two components, allowing high flexibility in choosing the desired range and precision.

In addition, a system based on a FPGA (Field Programmed Gate Array) is implemented to measure the oscillator period, display the data on a LCD screen, switch the probes for multiple measurements and send the measured data to a computer using serial communication for further analysis.

Its application for the calculation of some flotation variables (such as froth depth and gas hold-up) without requiring previous conductivity calibration is explained later.

2. Circuit description and principle of operation

The design of the proposed circuit is based on a simple square wave generator [20]. By generating a digital signal, it enables the transmission of signals a long distance, it is less sensitive to noise than analog signals, it is easy to make corrections if the signal has been corrupted and the period measurement is simpler than sinusoidal or triangular signals. Also, there is no need for an analog-to-digital converter to measure the signal, thus simplifying the design of the circuit. Fig. 1 shows the basic circuit, where R_e is a variable resistance to be measured. Operational

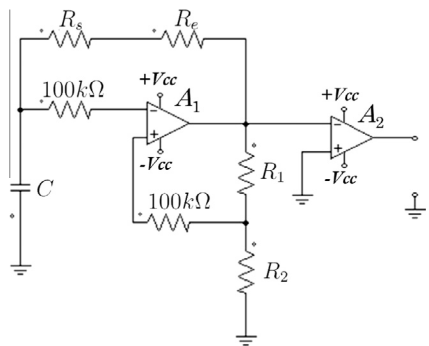

Fig. 1. Square wave signal generator. *Re* is a variable resistance (e.g. the conductivity cell, see Fig. 2).