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ON-LINE MICROWAVE MEASUREMENT OF THE MOISTURE CONTENT OF WHEAT

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In continuous grain drying fluctuations of the moisture content at dryer entrance are still a major problem resulting in under- or over-drying due to uneven moisture distribution at the discharge and, hence, lead to quality and economic losses. Recently, grain dryer producers increasingly apply direct on-line grain moisture measuring systems to improve dryer control. In the present study results of laboratory measurements of grain moisture content are presented based on the microwave resonator technique. These measurements carried out with wheat as test material are aimed to develop a new on-line grain moisture measuring system for dryer control. *Copyright © 2008 IFAC*

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1. INTRODUCTION

The need to measure and control the moisture content of wheat grain is now recognized as a necessary requirement to maintain competitive advantage in the food processing industry. Furthermore, the measurement technique employed must be cost effective, requiring rapid and accurate evaluation of the moisture content. In particular, non-invasive microwave techniques have received considerable attention in the literature and by industry (Haigh et al., 2001; Kraszewski, 1996; Kupfer et al., 2000).
Intending to control a grain dryer by an online moisture measurement, a collaboration of the Leibniz Institute of Agricultural Engineering Potsdam-Bornim (ATB) and the company TEWS Elektronik, Hamburg was started. The aim of this collaboration is the development of online moisture sensors for the inlet and the outlet of the grain dryer. The company TEWS Elektronik develops and supplies devices for the moisture measurement in a great variety of products. These devices all base on the microwave resonator technique, and thus this technique shall also be applied in grain dryers.
Test measurements of the moisture of wheat were carried out in the summer of 2007. The wheat was purchased by the ATB Potsdam. To reach high moisture levels, several samples of the wheat had been sprayed with water several days before the measurements. Other samples were dried before the measurements to reach low moisture levels. The moisture content of the wheat samples ranged from 7 to 29 % w.b. The reference moisture measurement was done by oven-drying according to DIN 10350 (Kocsis et al., 2007).

The measurements were carried out by use of a planar sensor TEWS P68-2 working in the frequency range of 2 – 3 GHz.

2. MICROWAVE RESONATOR TECHNIQUE

The microwave resonance technology utilizes the interaction between water molecules and changing electromagnetic fields. The measuring frequency of the employed stray field sensor is predetermined by the resonance wavelength of the microwave inducing resonator. The resonance frequency depends on the geometry of the sensor employed. If the resonator is loaded with materials, an increasing storage of electric field energy can be observed which leads to a decreasing resonance frequency (Buschmüller et al., 2007).

By use of the microwave resonator technique, on the one hand a moisture measurement can be realized which does not depend on the mass of the measured product. On the other hand, a measurement of the mass of the product, that is independent from its moisture, is possible as well. In the following, the basics of this measuring technique will be discussed.
A microwave resonator has got several resonance frequencies, e. g. certain frequencies with maxima of microwave transmission. The resonance frequencies depend on the dimensions of the resonator. For the measurements only one resonance is used. A resonance curve is characterized by two parameters (see Fig.1):

1. the resonance frequency,

2. the half-width of the resonance (width of the resonance curve at half level).

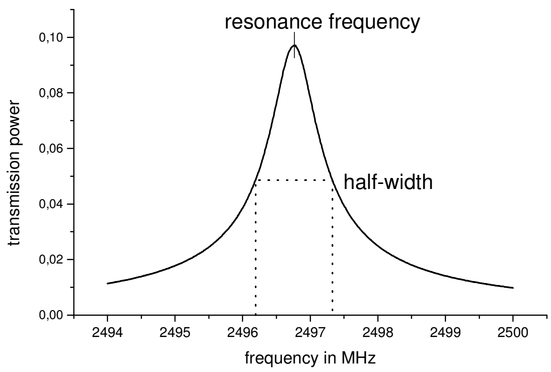

Fig. 1: Resonance curve

When material is placed in the measuring field of the resonator, the characteristics of the resonance curve change (see Fig. 2):

1. The resonance frequency decreases (due to a decrease of the wavelength inside the material).

2. The half-width of the resonance curve increases (due to losses of microwave energy inside the material).

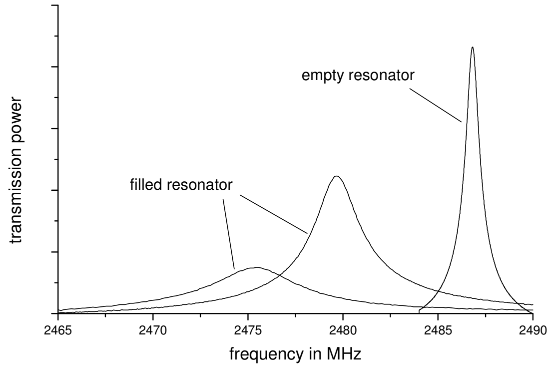

Fig. 2: Resonance curves of empty and filled resonator

As the moisture content increases the measured resonance curve moves to lower frequencies and the amplitude at resonance decreases (Knöchel et al., 2001) as shown in Fig. 2.

During the measurements changes of both parameters are detected. Thus, the measured values are the shift of the resonance frequency and the increase of the half-width of the resonance curve. So two parameters are measured and, hence, both unknown material parameters - the moisture content and the mass of the measured product - can be calculated.
As the changes of the resonance curve are detected during each measurement, the empty state of the resonator is also important for the measurement. Thus, the parameters of the resonance curve of the empty resonator have also to be detected. It is not necessary to carry out this empty state measurement before each measurement, but the empty state parameters are stored inside the microwave evaluation unit.

The evaluation of the measurement is introduced in the following:

1. The first measured parameter is the shift of the resonance frequency A in Hz:

$$A = f_0 - f_m$$

with f_0: resonance frequency of the empty resonator in Hz
f_m: resonance frequency of the filled resonator in Hz

2. The second parameter measured is the increase of the half-width B in Hz:

$$B = w_m - w_0$$

with w_0: half-width of the resonance of the empty resonator in Hz
w_m: half-width of the resonance of the filled resonator in Hz

3. Calculation of the mass-independent microwave-moisture-value Φ:

$$\Phi = \arctan (B/A)$$

The parameters A and B are both mass-dependent in the same way. Therefore, the quotient of A and B is mass-independent. It only depends on the moisture content of the material measured. The arc tangent of this quotient is calculated to reduce the codomain of the moisture value Φ: $\Phi \in [0, 1]$, Φ nondimensional.

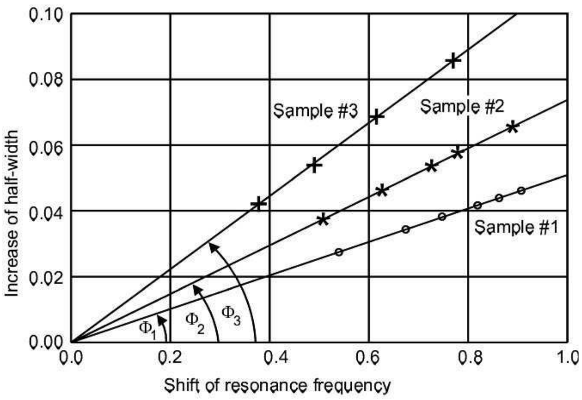

Fig 3: Measured parameters A and B for three samples with different moisture contents

Fig. 3 shows measured microwave parameters A and B for three samples with varying moisture contents:

moisture(sample#3) > moisture(sample#2) > moisture(sample#1).

Each sample was measured with varying mass situated in the measuring field. The more mass is situated in the field, the higher are the measured values of A and B. As can be seen from the figure, the calculated values Φ_1, Φ_2, and Φ_3 are independent of the mass situated in the resonator and depend only on the moisture content u of the material.
In most common cases, a linear calibration can be applied. For the moisture measurement in several materials, a non-linear calibration has to be chosen. In case of the measurement in wheat, a polynomial relation of second degree was applied (relation (1)):

$$u = a_1 \cdot \Phi^2 + a_2 \cdot \Phi + a_3 \quad (1)$$

with u: moisture content of the material in % w.b.
a_1, a_2, a_3: calibration coefficients
Φ: microwave-moisture-value

A calibration of the moisture measurement can also be realized by use of the frequency shift A or the increase of the half-width B. These calibrations are admittedly not independent of mass and density of the measured material, respectively. A calibration using the frequency shift A is given by relation (2) (Schlemm et al., 2007):

$$u = b_1 \cdot A + b_2 \quad (2)$$

with u: moisture content of the material in % w.b.
b_1, b_2: calibration coefficients
A: frequency shift in MHz

3. MEASUREMENTS

The measurements were carried out by use of a planar sensor TEWS P68-2 having several resonance modes in the frequency range of 2 – 3 GHz. Two resonance modes at 2,12 GHz and 2,81 GHz were used. Before the measurements the wheat samples were poured on the planar sensor. At each measurement, the shift of the resonance frequency A and the microwave-moisture-value Φ were detected. Each measurement was repeated for three to five times after redistributing the wheat on the sensor and the averages of the measured microwave values were calculated. Since the measuring results of the two resonance modes are quite similar, only the results of the mode at 2,81 GHz are presented in the following. The test measurements were carried out without variation of the grain temperature. The calibrations will have to be extended later by measuring the wheat at different temperatures.
Figures 4 and 5 show the measured averaged values of the frequency shift A and the microwave-moisture-value Φ of all measurements in dependence on the moisture content. These measuring values result from naturally moist wheat, dried wheat, and moistened wheat. Since the measuring values of A and Φ correspond quite well, the moistening or the drying obviously does not change the character of the bonds of the water molecules to the wheat. So it is possible for calibration purposes to dry or to moisten the grain.

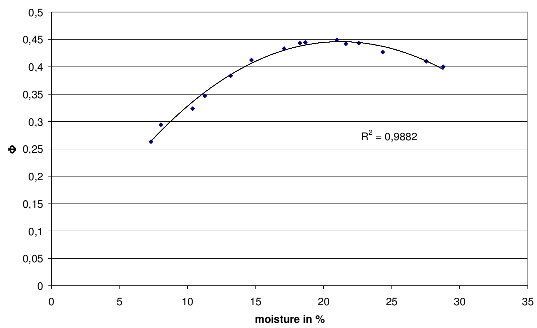

Fig. 4: Resonator P68-2, 2,81 GHz: microwave - moisture - value Φ in dependence on the moisture content, regression

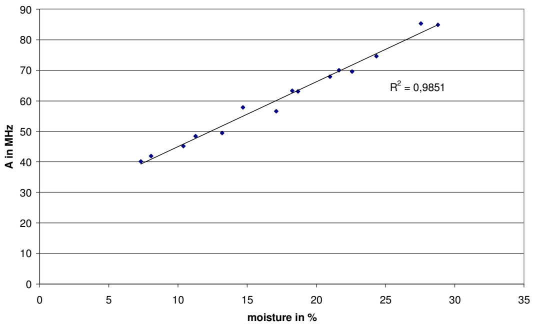

Fig. 5: Resonator P68-2, 2,81 GHz: shift of the resonance frequency A in dependence on the moisture content, regression

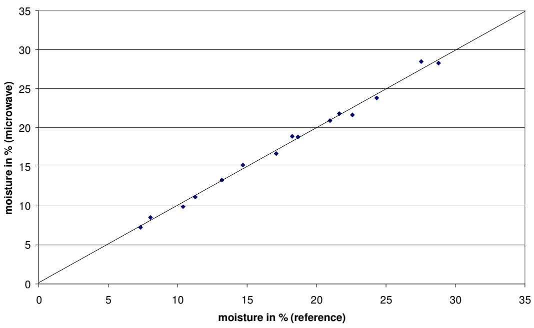

Fig. 6: Resonator P68-2, 2,81 GHz: results of the moisture measurements, SD = 0,51 % w.b.

In Figure 4 the microwave-moisture-value Φ is depicted versus the moisture content of the wheat. Since the value of Φ shows a maximum at moisture content of about 21 % a moisture measurement that uses the microwave-moisture-value Φ is only possible below moisture contents of about 18 %. This maximum results from the dielectric behaviour of moist wheat. Thus, this density-independent moisture measurement is suitable for the application at the outlet of a grain dryer, because the range of the moisture content at this position is limited. After one pass of the drying process, the moisture content of the grain will not exceed 18 %. Higher moisture contents can be found at the inlet of the dryer. Thus the moisture measurement that uses only the microwave-moisture-value Φ cannot be applied at the inlet of the dryer.

Figure 5 shows the frequency shift A in dependence on the moisture of the wheat. A moisture measurement that uses the frequency shift A is possible in the whole moisture range of 7 % w.b. to 29 % w.b. This moisture measurement is not independent of the density of the grain.

For the inlet of a grain dryer the two possibilities for the moisture measurement can be combined: For frequency shifts A up to 60 MHz (about 18 % moisture, see Figures 4, 5) relation (1) is applied, for frequency shifts A above 60 MHz relation (2). The result of this combined moisture measurement can be seen in Figure 6. The standard deviation between reference moisture and microwave-measured moisture content is sd = 0,51 % for the whole moisture range (7 - 29 % w.b.). The standard deviation for the density–independent measurement (relation (1)) up to 18 % w.b. moisture content is 0,39 % w.b. and for the not-density-independent measurement (relation (2)) above 18 % w.b. moisture content 0,63 % w.b. This result was achieved despite of variation of the density of the wheat at the sensor. The density-variation at a measuring position in a grain dryer is not expected to be significantly higher than the variation during these test measurements.

The result of the regressions for the calibration of the moisture measurements is the following:

For a moisture content from 7 to 18 % w.b. ($A < 60$ MHz) the following relation is valid:

$$u = 106{,}62 \cdot \Phi - 18{,}653 \cdot \Phi + 4{,}7705 \qquad (3)$$

Correlation coefficient: $R^2 =$ 0,988

For a moisture content from 18 to 29 % w.b. ($A \geq 60$ MHz) the following relation is valid:

$$u = 0{,}4349 \cdot A - 8{,}6209 \qquad (4)$$

Correlation coefficient: $R^2 =$ 0,973

4. CONCLUSION

For measurements of the grain moisture content at the inlet and the outlet of grain dryers, a planar microwave resonator was tested within a collaboration of the ATB Potsdam and the company TEWS Elektronik, Hamburg. Laboratory microwave moisture measurements were carried out with wheat samples in a wide range of the moisture content between 7 % w.b. and 29 % w.b. The measurements were conducted at 21°C ambient temperature. The standard deviation between the microwave-measured moisture content and the reference moisture content achieved was sd = 0,51 % w.b. for the whole moisture range. The measuring technique and the sensor applied are suitable for both measuring positions. It is necessary to apply different calibration relations for the inlet and the outlet of the dryer. In a next step the calibrations will be extended by measuring the wheat at different temperatures. Furthermore the measuring system will be tested in practice at an industrial grain dryer.

5. ACKNOWLEDGEMENT

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