DENSITY-INDEPENDENT MOISTURE METERING IN FIBROUS MATERIALS USING A DOUBLE CUT-OFF GUNN-OSCILLATOR

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Abstract

A new principle of density independent moisture measurement using microwaves at one frequency is developed. As a first application a double cut-off Gunn-oscillator was build, stabilized by adjacent modes of one measuring cavity containing the moistureous fibrous specimen.

Introduction

Conventional moisture meters suffer from changes in size of the respective specimen and variation in the density of the carrier substance. Typically they measure the absolute water content (m_{H_2O}/gr) in the measuring volume of the applicator. For determining the moisture ψ,

$$\psi = \frac{m_{H_2O}}{m_{dry} + m_{H_2O}} \tag{1}$$

the mass m_{dry} of the dry material (or its dry density ρ[gr/cm^3] = m_{dry}/volume) has to be known in addition, which can be gained with an independent measurement, e.g. by weighing or by i.r. techniques. In contrast to these complicated or time consuming and expensive procedures we present a new method and practical arrangement which allows the determination of the moisture content ψ by means of microwave measurements only, at least for a certain range of ψ and ρ.

Principle of Measurement

The working principle of the microwave moisture meter is based upon the fact that at microwave frequencies the complex dielectric constant of water (ϵ = 63-j31 at 9 GHz) markedly differs from that of many dry substances. Consequently the dielectric behaviour of the wet material depends in a very sensitive way on the moisture content, reflected in both the real and imaginary parts of the dielectric constant $\epsilon = \epsilon' - j\epsilon''$ (fig. 1).

For a wide variety of practically important materials [1], and for reasonably low moisture content, both ϵ'' and (ϵ' - 1) increase linearly with increasing density, i.e. the expression

$$A(\psi) = \frac{\epsilon'(\psi,\rho)-1}{\epsilon''(\psi,\rho)} \tag{2}$$

is independent of density. Therefore, by simultaneously measuring ϵ' and ϵ'' or adequate quantities of the wet sample, and calibrating the instrument in terms of $A(\psi)$, the relative moisture (ψ) can be determined below certain moisture levels.

The measurement of $A(\psi)$ is particularly simple in case of small specimen (e.g. fibres). According to perturbation theory [2] the complex dielectric constant of the (small) specimen is related to the change of the quality factor (Q) and the frequency (f) by

$$A(\psi) \equiv \frac{\epsilon'-1}{\epsilon''} = 2\,\frac{(f_2-f_1)/f_2}{(1/Q_1-1/Q_2)}\,, \tag{3}$$

where the indices 1 and 2 refer to the empty and the partially filled cavity.

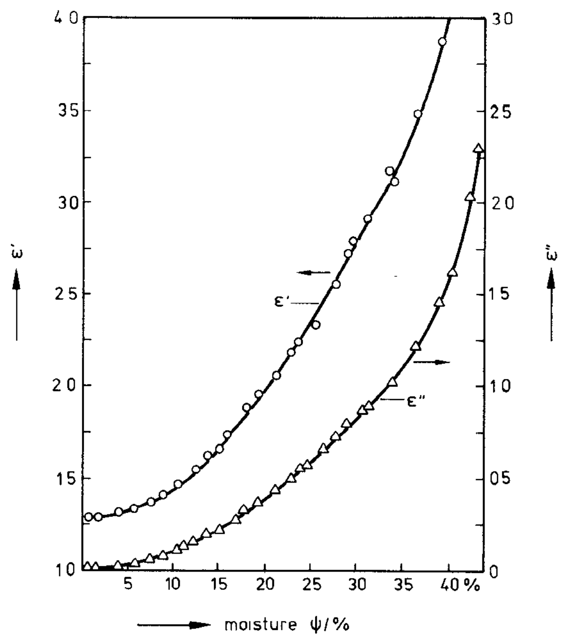

Fig. 1. Complex dielectric constant $\epsilon = \epsilon' - j\epsilon''$ of wet cotton (dry density, ρ = 0.24 gr/cm^3) at 10 GHz, measured in X-band waveguide bridge

Practical Arrangement

Cavity perturbation techniques have been used previously in determining the dielectric properties of materials [3], also of yarns and textiles [4], but merely on a laboratory scale and not with respect to moisture measurements. Our system, designed for industrial application (fig. 2), is a double Gunn-oscillator in cut-off technique. Its two oscillations are stabilized by adjacent modes of one cylindrical cavity, the H_{011}- and E_{012}-mode (fig. 3). The frequencies are centred around 11.5 GHz. By coaxially inserting the fibrous specimen, the E_{012}-oscillation is shifted in frequency whereas the H_{011}-resonance remains constant. The latter acts as the LO (local oscillator) at one port of a balanced mixer; at the mixer's output the E_{012}-power P and the difference of the two eigenmodes of the empty cavity is nearly temperature independent because the temperature drift of the cavity changes both frequencies simultaneously.

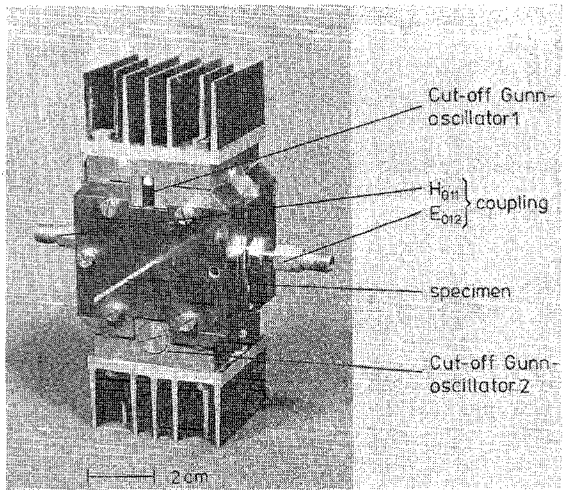

Fig. 2. Photograph of microwave moisture meter for fibrous materials (microwave part)

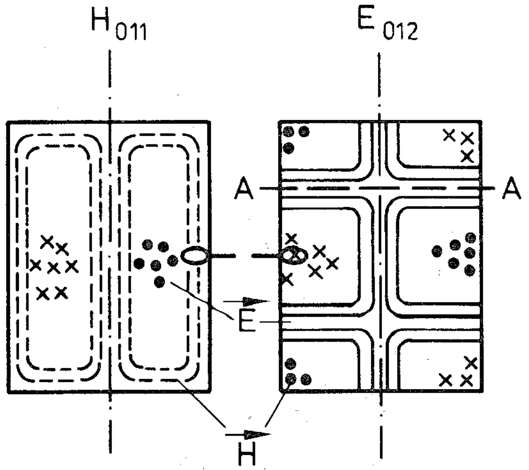

Fig. 3. Eigenmodes of cylindrical stabilizing cavity

Experimental Results

As the cut-off oscillator is a very broadband device [5], its output-power remains constant within ± 0.1 dB over a 50 MHz bandwidth when passively detuning the cavity by inserting a lossless dielectric. This is of fundamental importance because as a consequence the output power P is a monotoneous function of the dielectric loss ε" of the specimen and its water content (fig. 4). As the frequency shift Δf is an unambigeous function of ε'-1 or the water content (fig. 4), we arrive at a density-independent measure similar to equ. (3) by simply taking Δf/ΔP as a function of ψ. A comparison of values for (ε'-1)/ε" gained from frequency and quality measurements according to equ. (3), and Δf/ΔP measured in the double Gunn-oscillator described above are plotted in fig. 5 and exhibit nearly the same shape. As expected, both curves turn out to be independent of density of the carrier substance over a fairly wide range: Fig. 6 shows the variation of the frequency shift and the output power of the double Gunn-oscillator when the density of the cotton thread in the cavity is changed by a factor of 32. The result for Δf/ΔP is substantially constant at 7.5 ± 0.2 MHz/dB which equals a moisture content within the cotton of ψ = 4.5 percent with an experimentally determined error of Δψ = ± 0.1 percent over the whole density range.

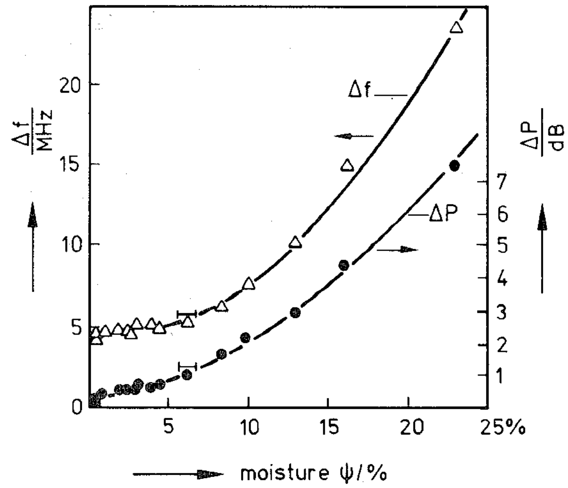

Fig. 4. Variation of differential frequency Δf and output power P of double-Gunn-oscillator, after inserting cotton threads with differing moisture contents ψ

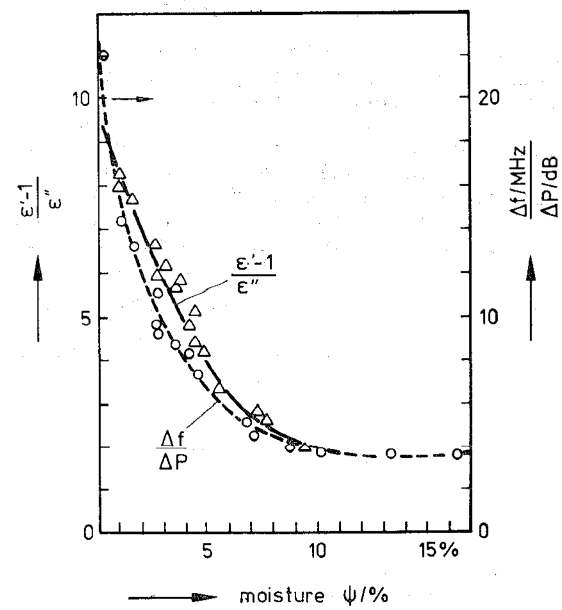

Fig. 5. Measured A(ψ) = (ε'(ψ)-1)/ε"(ψ) for cotton threads, as a function of moisture content, determined by
a) passive resonator method according equ. (3) (triangles)
b) active double Gunn-oscillator, Δf/ΔP

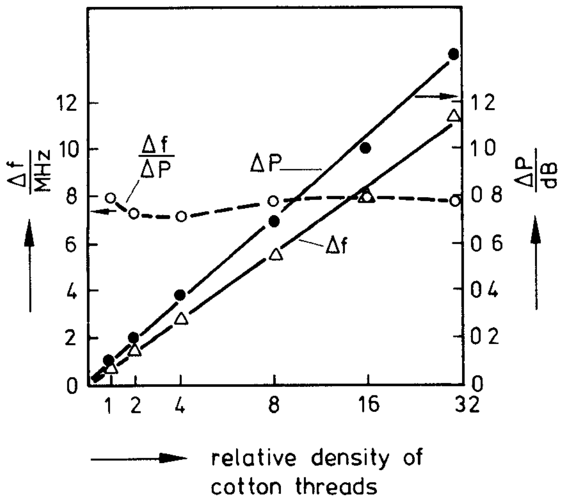

Fig. 6. Differential frequency Δf and output-power ΔP after insertion of different numbers of cotton thread of equal moisture content ($\psi \simeq 4.5\%$) into the stabilizing oscillator cavity

Conclusion

A new principle of density independent moisture determination has been worked out, based upon a two parameter microwave measurement at fixed frequency. As a first application a double cut-off Gunn-oscillator for measuring fibrous materials has been developed. Its feaseability for cotton threads has been proven; further applications are possible. The method for the first time brings about relative moisture measurement using microwaves at one frequency, without need for density and sample size correction.

References

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