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Contactless Thickness Measurements of Glass Walls by Using Microwave Reflections

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Abstract. In order to avoid damages and excessive materials consumption, during the production of glass containers it is important to keep limits for the glass wall thickness. Current methods do not offer satisfying solutions regarding contactless and fast measurements, as well as integration over sufficiently large areas. A new approach is the measurement by using microwave reflections. These reflections depend on glass thickness, frequency and on the distance between the sample and the sensor (liftoff). For the measurement of glass thickness the parasitic influence of the liftoff has to be eliminated. This paper describes a solution developed for this problem. Under certain circumstances, measurements of the complex reflection coefficient at constant frequency show a nearly orthogonal behaviour between lines of constant liftoff and lines of constant glass wall thickness. Therefore those two influences can be differentiated. After calibration with samples of known thicknesses, the thickness of an unknown sample can be determined by measuring its complex reflection coefficient. The solution was confirmed regarding reproducibility and accuracy of the results for flat glass plates. Present investigations are aimed at the extension of this method to curved glass walls.

Introduction

Limits for the glass wall thicknesses are important in the production of bottles and other glass containers. Thin glass for example could cause damage during the filling process or transportation, thick glass leads to excessive materials consumption. This could be avoided by controlling the wall thickness during the production process.

Presently there are various measuring methods, which are used, but they have different disadvantages. Some of them measure while contacting, so the glass could be scratched. Some measure on a very small spot, so a measurement is only possible on some positions or by using an array of sensors. [1]

Microwaves are used in various areas of NDT and have shown that a contactless measurement on a certain distributed area is possible. [2], [3]

The method presented in this paper is using microwaves for the measurement of glass wall thicknesses. Therefore an electromagnetic wave at a high frequency is irradiated to the sample and the complex reflection coefficient of the actual measuring situation is taken. This measured variable depends mainly on glass thickness, frequency and on the distance

between the sample and the sensor (liftoff). For an industrial application it is essential to eliminate the parasitic influence of the liftoff, because it cannot be ensured that it remains constant. So an appropriate method for measuring or interpretation is needed to differentiate the influences of liftoff and wall thickness. The best differentiation is given by an orthogonal behaviour between lines of constant liftoff and lines of constant wall thickness. If there is such a behaviour, several curves of constant wall thickness and variable liftoff can be created and the thickness of an unknown sample could be determined by comparing its complex reflection coefficient to those calibration curves.
For measurements presented in this paper an open-ended waveguide is used as transmitting and receiving antenna, connected to a network analyzer for measuring the complex reflection coefficient of a sample, located in a distance of few mm in front of the waveguide antenna (Fig. 1).

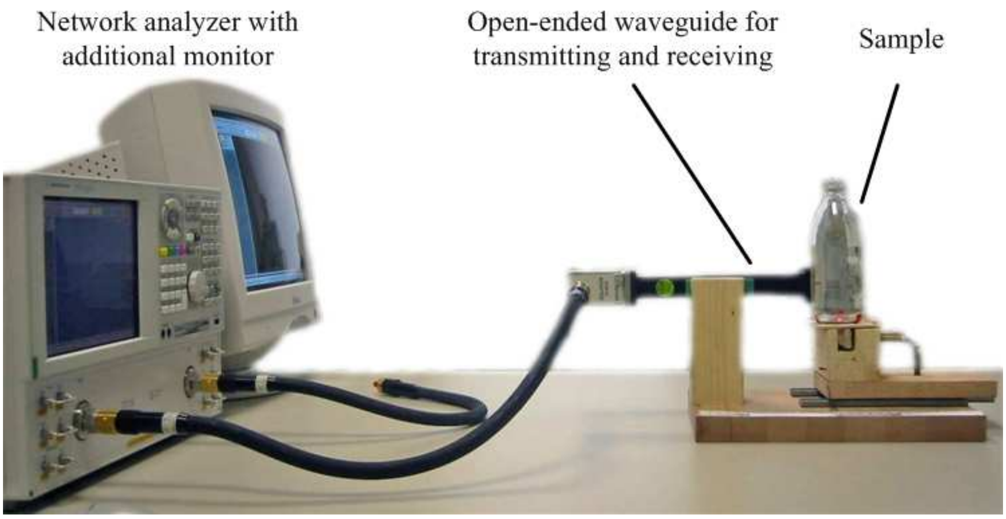

Fig. 1: Measurement Setup

Measurements at Flat Glass Walls

To simplify the measurement at first there were only flat glass plates used. There were several different glass plates available with thicknesses between approx. 1mm and 3mm. Their reflection coefficient was measured for various liftoffs at several constant frequencies.
The best orthogonal behaviour was located at X-band frequencies, especially in a frequency range of 9GHz to 11GHz. The following results focus on a measurement frequency of f=11GHz, where the best results were achieved. Similar measurements were also performed at frequencies of 8GHz, 9GHz, 10GHz and 12GHz.
To examine the accuracy and reproducibility of this method, the complex reflection coefficients of glass plates with thicknesses d = 0.985, 1.09, 1.25, 1.83, 2.856mm were recorded at liftoffs = 0, 0.5, 1,…, 5, 5.5mm (Fig. 2). The thicknesses were mechanically measured wit a micrometer screw.

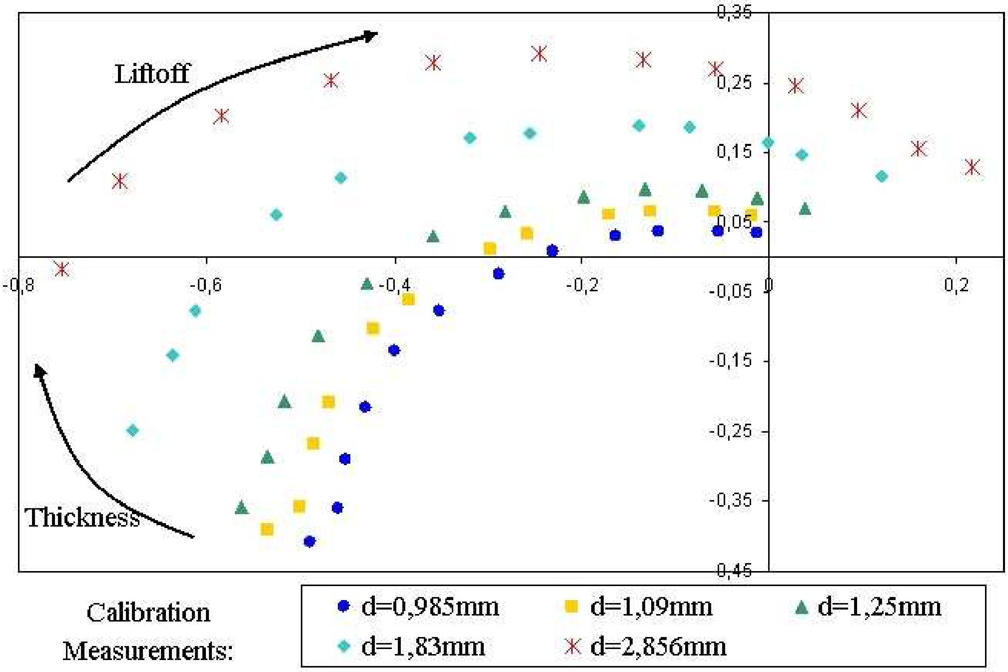

Fig. 2: Complex plane of the reflection coefficient. Calibration measurements of the complex reflection coefficient of 5 flat glass plates as calibration plates

Using these measured data, curves of constant glass wall thickness and variable liftoff were created. It is also necessary to determine glasses with thicknesses not calibrated with, so several curves within a range of d = 1…2.8mm and variations of Δd = 0.1mm were calculated by interpolation. Those curves were added to the diagram of measured data. (Fig. 3)

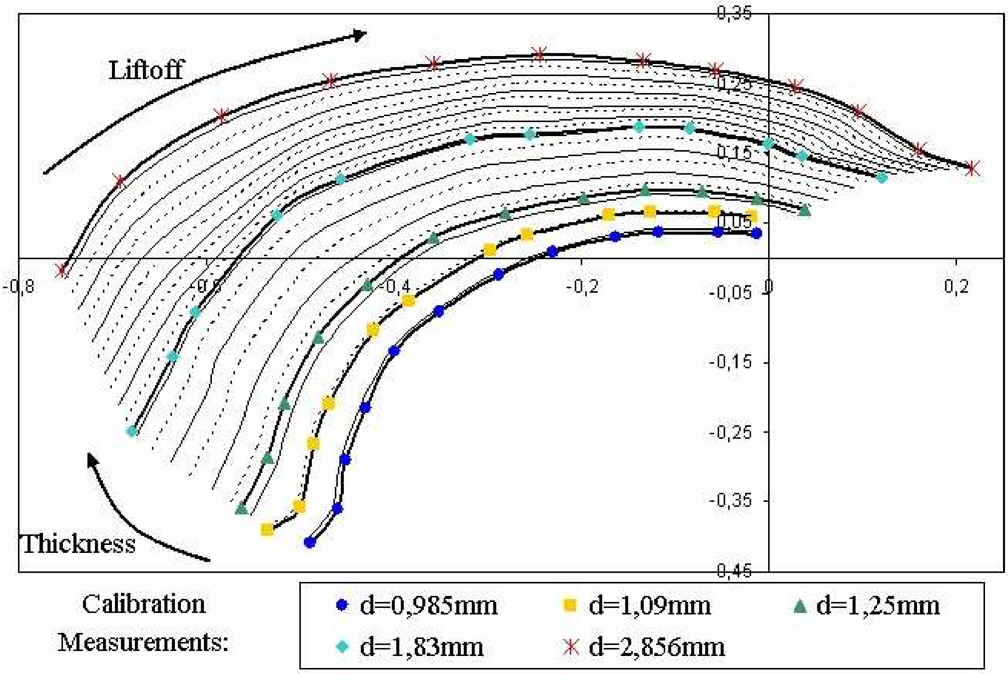

Fig. 3: Complex plane of the reflection coefficient. Lines of constant thickness and variable liftoff for calibration from measurements and interpolation

In this diagram it can bee seen, that the various curves, representing various thicknesses, show a regular behaviour. Variations of the liftoff are rather presented in changes of the

imaginary part and variations of glass wall thickness are rather presented in changes of the real part of the complex reflection coefficient. Also none of these curves are intersecting each other, so from a measured reflection coefficient the wall thickness results as a single-valued function within the entire examined range of thickness- and liftoffvariations.
With increasing wall thickness the differentiation becomes more difficult, because the calibration curves are closer together. It also becomes more complicated with an increasing liftoff, because the received signal is more attenuated, probably due to higher radiation losses.
To test the created calibration curves, blind measurements on glass plates were performed, i.e. without the knowledge of the liftoff. Therefore the 5 calibration plates and one further plate were used. These samples were measured at 5 different unknown liftoffs and the resulting reflection coefficients were inscribed into the calibration diagram. (Fig. 4)

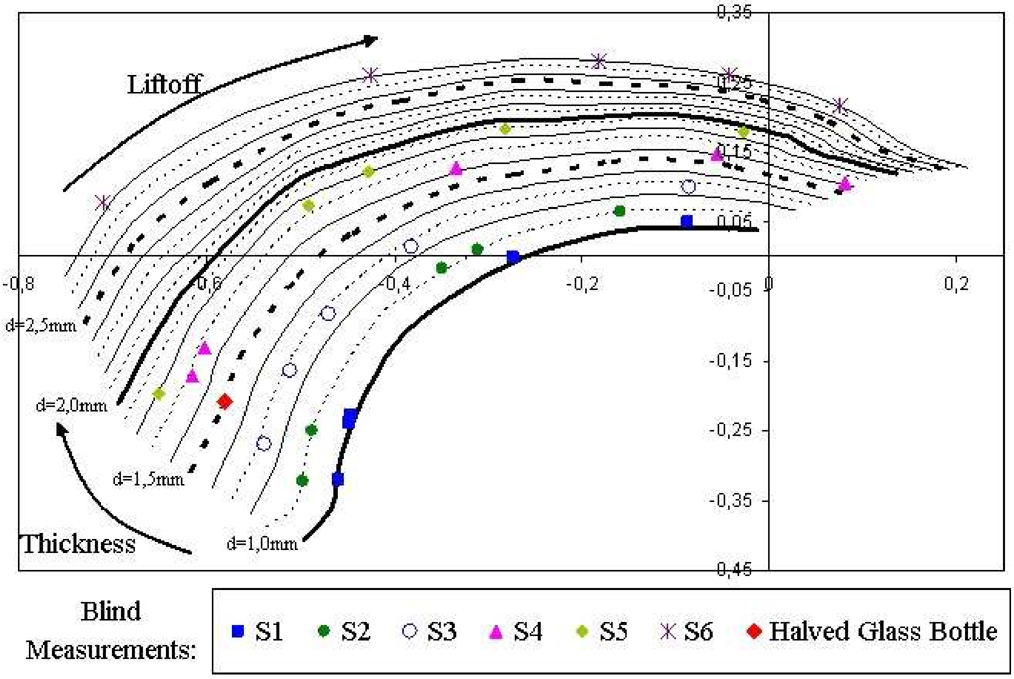

Fig. 4: Complex plane of the reflection coefficient. Measurements of glass plates with unknown thickness and liftoff

The wanted thickness can now read off this diagram (Table 1)

Table 1. Concluded thicknesses

Sample No.		**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Mechanically measured thicknesses in mm		***0.985***	***1.09***	***1.25***	***1.65***	***1.83***	***2.85***
Thicknesses in mm as derived from calibration curves (Fig. 4) for various liftoffs (I-V)	**I**	1.00	1.10	1.30	1.70	1.80	2.85
	II	1.00	1.10	1.30	1.70	1.75	2.85
	III	1.00	1.10	1.25	1.65	1.80	2.80
	IV	1.00	1.10	1.25	1.60	1.90	2.80
	V	1.05	1.10	1.25	1.60	1.90	2.80
Maximum deviation in mm		0.065	0.01	0.05	0.05	0.08	0.05

The achieved results show deviations of less than 0.1mm, which will normally be acceptable.

Measurements at Curved Glass Walls

The calibration curves created with flat glass plates can also be used for measuring curved glass walls. This is can be seen in Fig. 4, where a blind measurement was performed to determine the wall thickness of a halved bottle with a mechanically measured thickness of about 1.5mm. This thickness can also determined from the flat glass plate calibration curves created at other frequencies. (Table 2)

Table 2. Thickness of a halved glass bottle (d≈1.5mm) determined from calibration curves from flat glass plate measurements at various constant frequencies

f in GHz	d in mm
8.2	1.45
9.0	1.5
10.0	1.5
11.0	1.5
12.0	1.45

By measuring an intact glass bottle, a frequency-dependence appears. This frequency-dependence can be seen particular by looking at a diagram of the complex reflection coefficient with frequency variations. In contrast to measurements on flat glass plates the complex reflection coefficient for a glass bottle show a more curly graph. (Fig. 5, Fig. 6)

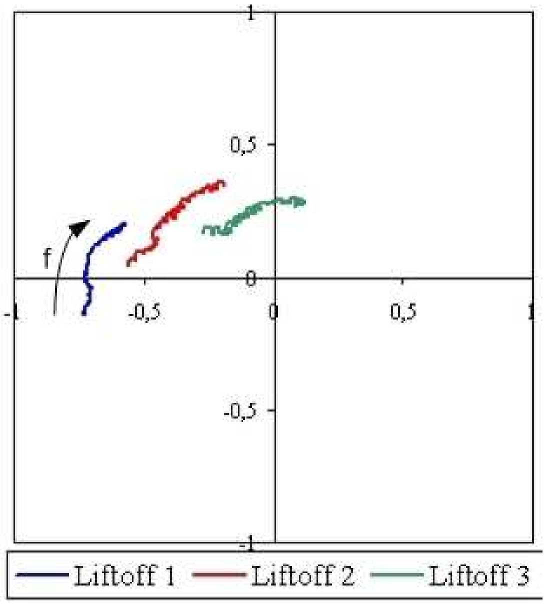

Fig. 5: Complex reflection coefficient of a flat glass plate (d=2.85mm) at f=8.2…12.4GHz for various liftoffs

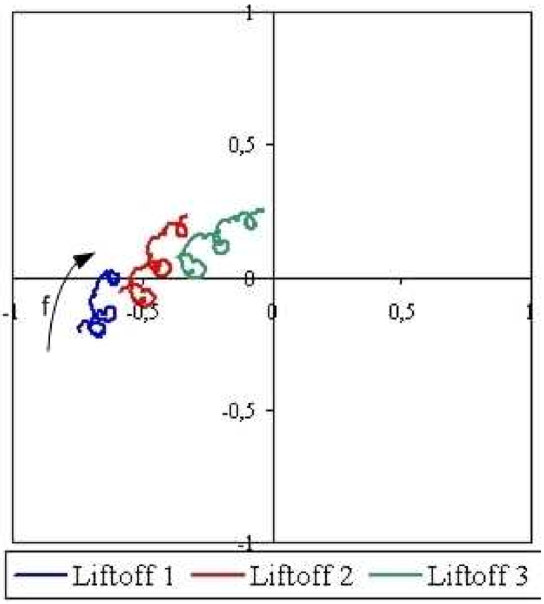

Fig. 6: Complex reflection coefficient of a glass bottle (d≈2.9mm) at f=8.2…12.4GHz for various liftoffs

The reason for this effect lies in the interaction of wanted reflections from the front and unwanted reflections from side and back of the glass container. Because of this effect, calibration curves created by measuring flat glass plates produce ill-defined results for glass containers. Those unwanted reflections have to be suppressed, e.g. by use of a proper antenna structure. It is expected that in this case calibration curves can be used which are based on flat glass plates.

Conclusion

This paper describes a method for measuring glass wall thicknesses by using microwave reflections. It has shown good results on flat glass plates concerning accuracy and reproducibility. An adaption for measuring container glass is possible, but further development is necessary.
This method has potential to be used also for measuring wall thicknesses of other non-conductive materials, e.g. plastics, because those are, like glass, almost transparent for microwaves.

Acknowledgment

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