MICROSTRIP NONCONTACTING THICKNESS MONITOR

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ABSTRACT

A microwave technique for measurement of the height of a material on a metallic surface using a planar microstrip transmission line structure is presented. A device was designed to monitor the height of a film of water up to about 1 mm. The method produced consistant results and may be adapted for use without microwave frequency measurement devices.

INTRODUCTION

We describe a noncontacting microwave method of measuring the thickness of a thin layer of fluid, or the thickness of a solid coating on a surface, or the change in height of a surface. An apparatus employing this technique could find application in the coating industry, in falling film vapor reactors, in trickle bed chemical reactors, and in other applications in which coating thicknesses or changes in location of a tenth of a millimeter to several millimeters are to be determined.

One of us (RPR) has investigated a number of other methods of measuring the thickness of such a film of water, including capacitive probes or fluorescent emission. These other methods were found to be either of very questionable accuracy, or quite expensive or not applicable to most practical situations.

THEORY

Our technique makes use of the fact that the velocity of propagation along a microstrip line depends on the dielectric constant and the physical distribution of the media that are in the vicinity of the strip conductor. Consequently, if the strip of the transmission line is above a metal surface that is coated with a material (either insulating or conducting), a measurement of the propagation velocity of an electromagnetic wave propagating along this configuration can be translated into the thickness of the coating.

The specific problem that we set out to solve was to find a noncontacting method of measuring the height of a film of water. The work to be described deals specifically with this problem. As such, it can be considered an extension of the microwave aquametry work conducted in the 1970's [1-3]. The difference is that aquametry deals with the sensing of the percentage of water in a material, while in our work it is the thickness of a film of water, or other material, that is to be measured.

PHASE DEPENDENCY

The transmission line configuration for the constructed monitoring device is shown in Figure 1.

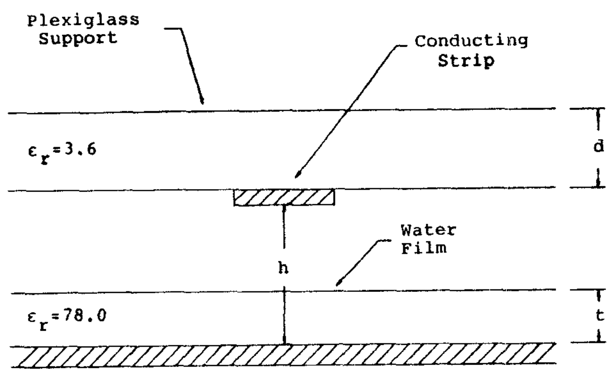

Figure 1. Plexiglass Supported Strip

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As seen, the transmission line resembles an inverted microstrip transmission line structure. To correlate experiment with theoretical expectations, Wheeler's method of finding effective dielectric constant by calculating capacitances of both empty line and line with dielectric material in place [4] was used to predict the relative phase constant $\beta/\beta o$, assuming the dielectrics to be lossless. (Here βo is the phase constant for the microstrip line without dielectric.) The calculated dependence of the relative phase constant on water height is shown in Figure 2.

RELATIVE PHASE CONSTANT vs WATER THICKNESS

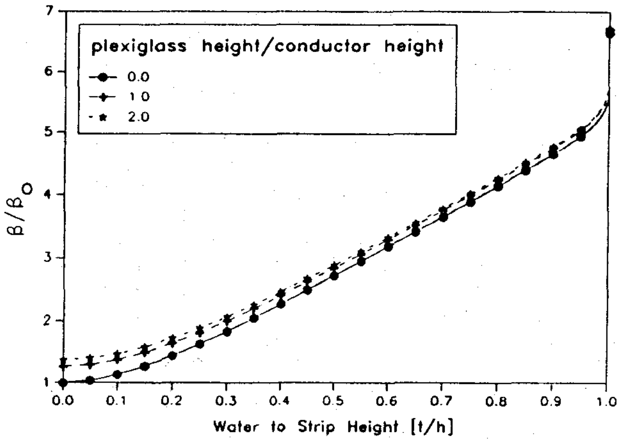

Figure 2. Calculated Phase Constant

It was found that this solution of Laplace's Equation modeling did not quite match the experimental results for our line structure. A modification was required to account for the effect of losses in the water which produced a better approximation of the transmission line phase constant.

The phase of the impedance of an open transmission line suspended above a water film on the plate was measured using a network analyzer. A sketch of the line support structure and plate is shown in Figure 3. The plate dimensions were approximately 6" by 12" while the supporting structure for the open line extended about 3 mm above the surface of the plate.

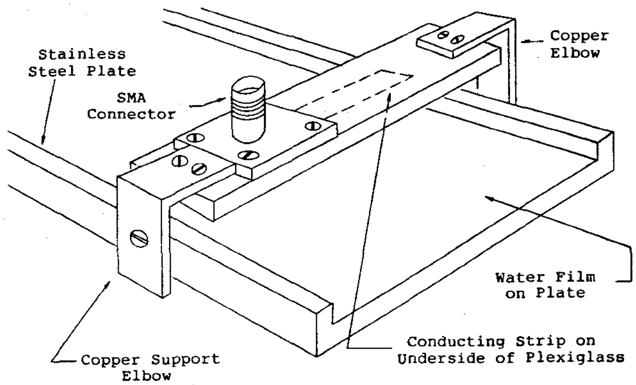

Figure 3. Open Line and Plate

Measurements at 400 MHz were taken for the phase and correlated with a measurement of the film height by use of a micrometer. The phase of the open line impedance decreased steadily as the height of the film was increased. This is shown in Figure 4.

IMPEDANCE PHASE CHANGE OF OPEN STUB

(Note: strip width is .5")

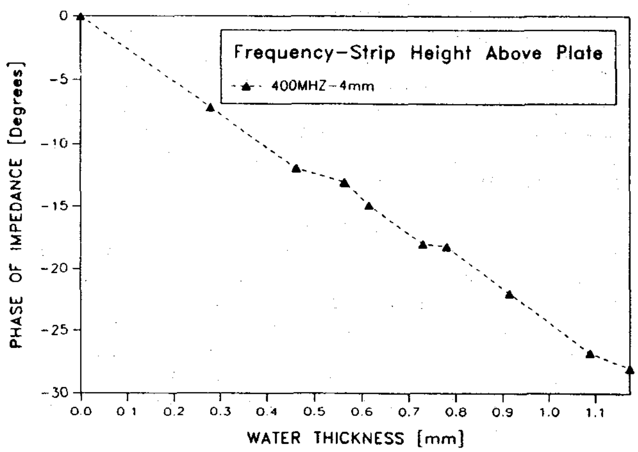

Figure 4. Phase of Open Line Impedance Relative to the Dry Plate

MONITORING BY RESONANCE

Measurement of microwave phase requires sophisticated equipment, which is costly and is difficult to operate without prior experience. To eliminate the need for a network analyzer, a second method to monitor film height was investigated. In this method the phase constant, which varies with film height, is noted to influence the resonant frequency of a lightly coupled transmission line resonator. When such a resonator is properly connected to an amplifier with sufficient positive feedback, the amplifier will oscillate at the frequency of the resonator. By use of a microwave discriminator [5], the deviation in the oscillator frequency from the frequency of a reference cavity can be converted into a DC voltage, which can then be displayed on an ordinary DC meter.

A structure that was used to investigate the change in resonant frequency with film height is shown in Figure 5.

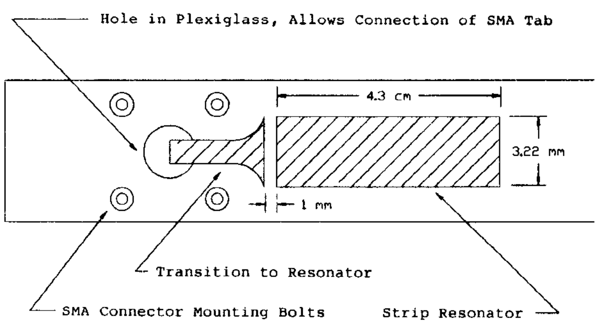

Figure 5. Experimental Resonator

The dry resonant frequency of the plate assembly was measured at 2.65 GHz. The resonator frequency versus water film height was measured for two sets of data with water heights up to about 1 mm. A micrometer was again used to measure the physical height of the water film. The results for each set of data is shown in Figure 6.

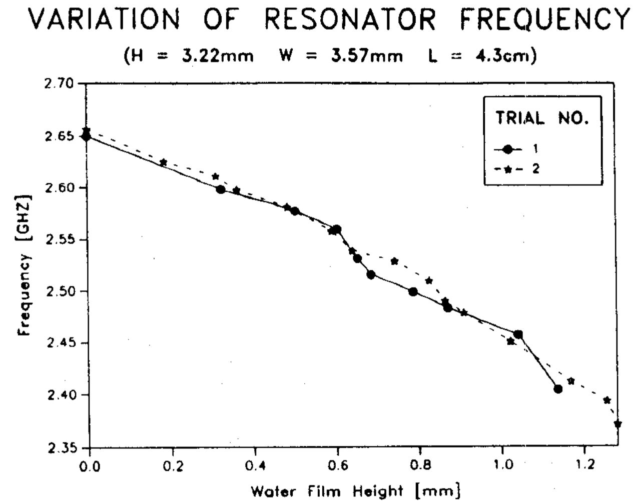

Figure 6. Resonator Frequency

The resonator frequency was found to vary linearly with water height and produced consistant results between data trials.

In the work described the quantity monitored was the height of a water film on a metallic ground plane. Such a ground plane should not be necessary, however. The same type of noncontacting measurements may also be possible with other types of strip lines not requiring the presence of a ground plane, such as slot line or coplanar waveguide.

SUMMARY

We have demonstrated a technique for using a measurement of microwave propagation velocity to determine the height of an adjacent film of water. This technique can be used to construct noncontacting height or thickness measuring instruments for a number of industrial and research applications.

REFERENCES

[1] M. Kent and T.E. Price,"Compact Microstrip Sensor for High Moisture Content Materials," JOURNAL OF MICROWAVE POWER, vol. 14(4),pp. 363-365:1979.

[2] M. Kent,"The Use of Strip-Line Configuration in Microwave Moisture Measurements II",JOURNAL OF MICROWAVE POWER, vol. 8(2), pp. 189-194: 1973.

[3] A. Klein,"Microwave Moisture Determination of Coal-a Comparison of Attenuation and Phase Measurements," CONFERENCE PROCEEDINGS OF THE 10TH EUROPEAN MICROWAVE CONFERENCE, WARSAW, POLAND, 8-12, SEPT. 1980, pp. 526-530:1980.

[4] K.C. Gupta, Ramesh Garg and I.J. Bahl,MICROSTRIP LINES AND SLOTLINES, pp. 7-15:1979.

[5] Om P. Gandhi, MICROWAVE ENGINEERING AND APPLICATIONS, pp. 190-196: 1981.