Waveguide method for measuring dielectric constant of asphalt concrete at 2.45GHz

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Abstract: -A method for determining the dielectric constant of asphalt concrete is described in this paper. In the measurement, the asphalt concrete is fused into the sample-holder waveguide and the asphalt concrete is full filled the certain length waveguide. The reflection coefficient of the sample in the waveguide is measured by Hp8719C. With our optimized waveguide method, a practical algorithm is developed to retrieve the dielctric constant from the measured reflection coefficient.

Key-Words: - Dielectric constant, Asphalt concrete, Rectangular waveguide, Reflection coefficient

1. Introduction

The study of measuring constitutive parameters of asphalt concrete is motivated by the application of microwave to heating asphalt concrete road require a knowledge of the permittivity of the involved concretes. In the past, though many dielectric measurement techniques have been reported, such as the open-coaxial method[1],resonant methods[2,3], free-space techniques[4], the waveguide transmission-reflection method is wildly used in microwave industrial processing of materials(drying,heating). With current computer and vector network ananlyzers, the measurement can be conducted with a high degree of automatization and accuracy.

2. The waveguide measurement theory and method

Waveguide methods for measureing the dielectric constant of materials are well known and have been used for a long time. Several methods employing a waveguide as a sample-holder for determining the permittivity of a sample have been described in[5]. The asphalt concrete is fused and full filled the certain length waveguide, as shown in Fig.1. The width and height of the asphalt concrete sample are a and b, respectively. The incident wave of TE_{10} mode, propagating in the z-direction, is given by

$$\begin{cases} H_x = jk_1 \dfrac{a}{\pi}\sin\dfrac{\pi}{a}x; H_y = 0; H_z = \cos\dfrac{\pi}{a}x \\ E_x = 0; E_y = -j\omega\mu\dfrac{a}{\pi}\sin\dfrac{\pi}{a}x\ ;\ E_z = 0 \end{cases} \quad (1)$$

Where $k_1 = \sqrt{k_0^2 - (\pi/a)^2}$ and $k_0 = \sqrt{\omega^2\mu_0\varepsilon_0}$, at the surface of z=0 the electromagnetic field satisfy the boundary condition

$$\begin{cases} \varepsilon_0 E_{1z} = \varepsilon_0\varepsilon_r E_{2z} \\ \mu_0 H_{1z} = \mu_0\mu_r H_{2z} \\ E_{1\perp} = E_{2\perp} \\ H_{1\perp} = H_{2\perp} \end{cases} \quad (2)$$

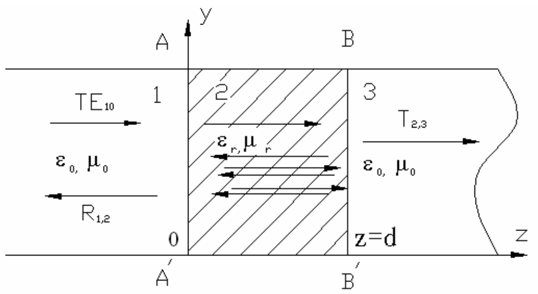

Fig. 1 Sample placement for TR measurements

If the length of the sample is infinit, from the equation(1)and (2),yielding the translating field in area 2 given by

$$\begin{cases} H_z = B_{10}\dfrac{2k_1}{k_2 + k_1\mu_r}\cos\dfrac{\pi}{a}x \\ H_x = jk_1\dfrac{a}{\pi}B_{10}\dfrac{2k_1}{k_2 + k_1\mu_r}\sin\dfrac{\pi}{a}x \\ E_y = -j\omega\mu_r\dfrac{a}{\pi}B_{10}\dfrac{2k_1}{k_2 + k_1\mu_r}\sin\dfrac{\pi}{a}x \\ E_z = 0; H_y = 0; E_x = 0 \end{cases} \quad (3)$$

Where $k_2 = \sqrt{k_0^2\mu_r\varepsilon_r - (\pi/a)^2}$ and ε_r, μ_r is the relative permittivity and permeability of the sample(area2). For it is supposed the length of area 2 is infinit, the reflect field is given by

$$\begin{cases} H_z = A_{10}\dfrac{\mu_r - G}{\mu_r + G}\cos\dfrac{\pi}{a}x \\ H_x = jk_1\dfrac{a}{\pi}A_{10}\dfrac{\mu_r - G}{\mu_r + G}\sin\dfrac{\pi}{a}x \\ E_y = -j\omega\mu_r\dfrac{a}{\pi}A_{10}\dfrac{\mu_r - G}{\mu_r + G}\sin\dfrac{\pi}{a}x \\ E_z = 0; E_x = 0; H_y = 0; G = k_2/k_1 \end{cases} \tag{4}$$

With the boundary condition and suppose $\mu_r = 1$, we derived the following expressions

$$\begin{cases} A_{10} = \dfrac{\sqrt{k_0^2 - (\pi/a)^2} - \sqrt{k_0^2\varepsilon_r - (\pi/a)^2}}{\sqrt{k_0^2 - (\pi/a)^2} + \sqrt{k_0^2\varepsilon_r - (\pi/a)^2}} \\ B_{10} = \dfrac{2\sqrt{k_0^2\varepsilon_r - (\pi/a)^2}}{\sqrt{k_0^2 - (\pi/a)^2} + \sqrt{k_0^2\varepsilon_r - (\pi/a)^2}} \end{cases} \tag{5}$$

As shown in fig.1 the sample's length is not infinit, there is another boundary at $z = d$ and the waveguide has three areas,the area1 contains air, the area 2 contains the sample, the area 3 contains air again. When the incident wave of TE_{10} mode, propagating to the boundary of area 1 and 2, the boundary splitting the field into reflect field A_{10} and transmission field B_{10}, the transmission field reaching to the boundary of area 2 and 3,the field splitting again, the reflect field is C_{10} and transmission field is D_{10}, the reflect field C_{10} will be splitted by the boundary of area1 and 2, in this way, the incident wave is splited by the two boundary and comes to a balanced status in the end. As shown in fig.2 the Hp8719C can be used for measuring the total reflect field $R_{1,2}$, and the total transmission field $T_{2,3}$. The expressions for $R_{1,2}$ and $T_{2,3}$ are as follows:

$$R_{1,2} = A_{10} + D_{10}B_{10}e^{-jk_2d}\cdot\sum_{p=0}^{\infty}\left(e^{-jk_2d}C_{10}\right)^{2p+1} \tag{6.a}$$

$$T_{2,3} = \left[C_{10}B_{10} + D_{10}B_{10}\cdot\sum_{p=0}^{\infty}\left(e^{-jk_2d}C_{10}\right)^{2p}\right]\cdot e^{-jk_2d} \tag{6.b}$$

Where $D_{10} = 1 - A_{10}$; $C_{10} = -A_{10}$, from (6) derives

$$R_{1,2} = A_{10} + \frac{A_{10}\left(A_{10}^2 - 1\right)e^{-2k_2d}}{1 - e^{-2k_2d}A_{10}^2} \tag{7}$$

$$T_{2,3} = \frac{\left(1 - A_{10}^2\right)e^{-2k_2d}}{1 - e^{-2k_2d}A_{10}^2} \tag{8}$$

Substitute different value of complex permittivity among a estimated region into one of the equation (7)or(8), the most acurate value induced the measurement $R_{1,2}$ or $T_{2,3}$ can be calculated by cumputer program. And then the dielectric constant of asphalt concrete can be figured out.

3. Measurement procedure and results

In this section, the rectangular waveguide measurement theory and method is examined by experiments. As shown in Fig.2 and Fig.3, The rectangular waveguide sample-holder is connected to the measuring chain, consisting in a VNA Hp 8719C , a coaxial waveguide transition and a matched load. The measurement plane is set on A-A'(z=0) as shown in Fig.1. The systematic errors, known as directivity, source mismatch and frequency tracking, are removed by the full one-port calibration procedure using calibration kids included a short, an open line and a matched load.

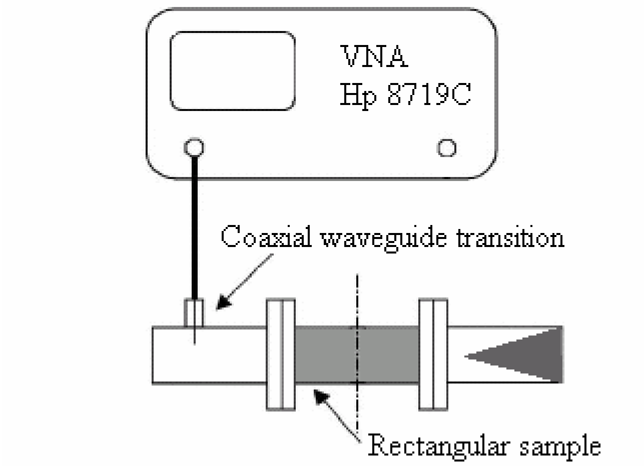

Fig. 2 Measurements of $R_{1,2}$ with a VNA

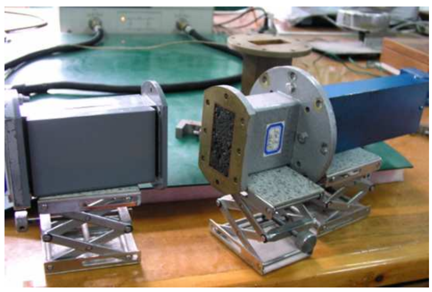

Fig. 3 The rectangular sample-holder

Simultaneous measurements of $\varepsilon = \varepsilon' - j\varepsilon''$ are generally performed by placing a rectangular sample with the same shape of the waveguide-holder[6] and refering to complicated equations to solve the problem. In microwave industrial processing, the asphalt concrete is fused into the sample-holder waveguide and the asphalt concrete is full filled three defferent length sample-holder rectangular waveguide in this measurement. The permittivity values in a estimated region could be substituted into equation (7) or (8) by computer program, untill we get the nearest value of $R_{1,2}$ with the data measured by Hp 8719C. As shown in Fig.5 the equation (7) is applied to retrieve the permittivity in this measurement.

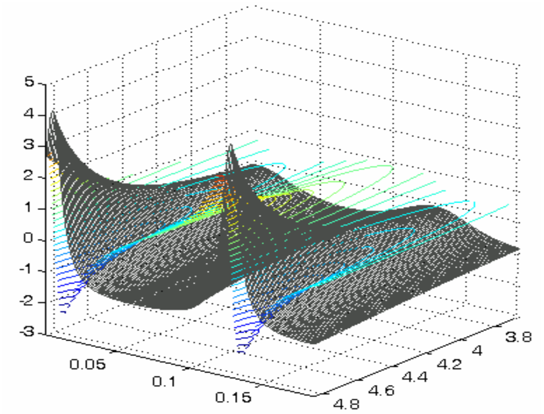

Fig. 5 Computer retrieving the dielctric constant

The measurement results of asphalt and basalt mixture concrete are listed in table 1.

Table 1. The measurement dielctric constant of the asphalt concrete

Length (mm)	300	200	100
f	2.45GHz	2.45GHz	2.45GHz
S_{11}	0.6790 □80.56°	0.6601 □62.60°	0.1491 □12.69°
ε_r/tgδ	3.86 +9.10e-002i / 2.355e-002		
f	2.2G	2.2G	2.2G
S_{11}	0.1937 □56.03°	0.212 □146.2°	0.4536 □90.15°
ε_r/tgδ	4.61+8.00e-003i / 1.735e-003		

4. Conclusion

In this paper , a dielectric constant measurement technique for asphalt concrete is presented. To eliminate the aperture between the asphalt concrete sample and the rectangular waveguide sample-holder, the asphalt concrete is fused into the sample-holder waveguide and full filled three different length waveguide sample-holder. The permittivity values in a estimated region could be tested to get the nearest value with the measured reflection coefficient. The permittivity retrieve processing is automatically done by computer program and could be used in microwave industrial processing of materials.

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