MICROWAVE NONDESTRUCTIVE TESTING OF DIELECTRIC MATERIALS

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Summary The article focuses on measurements on pertinax and polyethylene samples to obtain their material characteristics by means of microwave investigation. Evaluation of the results is performed and accuracy possibilities are discussed. The influence of free holes and longitudinal cracks in pertinax on the reflected microwave signal is investigated. Also in the same way holes in teflon sample filled with the metal powder are irradiated with microwaves and the reflected signal is followed up. The measuring results are plotted in graphs. Also some comparisons of NDT methods are given.

1. INTRODUCTION

There is a wide range of technology which might be described as nondestructive testing (NDT). The core of “traditional” NDT is commonly thought to contain visual, ultrasonic, eddy current, liquid penetrant, and magnetic particle inspection methods. Other methodologies include: acoustic emission, use of laser interference, microwaves, NMR, thermal imaging, etc. These and other NDT methods are gaining in numbers of regular applications. No single technology can be expected to solve all of the complex problems that are associated with NDT and complementary capabilities of a variety methods is often required to solve the NDT problem.

Microwave techniques have been placed under the rubric “other NDT”. Actually, applications for solving practical problems nonintrusively with microwave – based NDT have proven to be powerful, especially for the defectoscopy of parts made from plastics and fibre – reinforced plastic. For weight reduction purposes such materials are more and more used in fields of automobile and aerospace technology.

Up to now, however, microwave defectoscopy represents itself more an academic research topic than a routine procedure for practical applications. The reasons for this are probably that the microwave technique and interpretation of the test results seem to be complicated.

Microwave signals penetrate dielectric media relatively easily. The actual depth of penetration is dictated by the loss factor of dielectric and frequency of electromagnetic radiation. Measurements may be conducted as either contact or noncontact and with access to one side only (reflection) or using both sides of the inspected object (transmission). Microwaves NDT techniques are sensitive to geometrical and dielectric variations in a sample (including influence of flaws and defects). Polarizations properties of microwave signal can be used to increase the sensitivity to defects and flaws of certain orientation in the sample.

There appears to be misconception that, because microwave signal may have wavelengths of the order of centimeters, the resolution of flaws and defects is limited to a large fraction of these relatively long wavelengths. Actually, defects such as cracks in metals or thickness variations in dielectric coatings as small as few microns have been measured using microwave wavelengths of few centimeters. Even information about NDT of closed fatigue cracks and corrosion cracks on metal surface by microwaves have occurred.

These and some others reasons led us to pay attention to microwaves not only theoretically, but also to make use of their larger abilities experimentally.

The research in microwaves we have divided in two successive stages:

- NDT of nonconducting materials, and
- NDT of other materials, including metals

In this article we pay attention to the first one.

2. EXPERIMENTS AND RESULTS WITH DISCUSSION

Directing microwave NDT at plastics demands the knowledge of their material characteristics, which from the standpoint of the interaction of microwave signal with the dielectric are two complex constants: complex permittivity $\varepsilon = \varepsilon' - j\varepsilon''$ and complex permeability $\mu = \mu' - j\mu''$. Since the materials taken into account in this article are considered to be nonmetallic, $\mu = \mu_0$ (permeability of the free space).

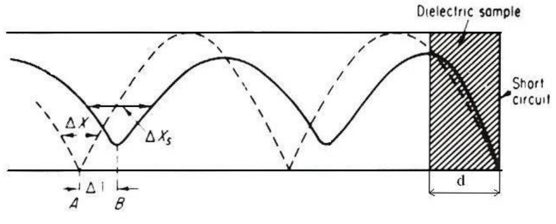

Fig. 1. Standing waves in the waveguide with (solid line) and without (dashed line) the sample

First we made use of determining complex permittivity the shorted – line technique, where a slotted section is used to measure the shift of minimum position of a standing wave and the change in the standing – wave ratio. The minima of the standing – wave pattern occurs at intervals of one-half wavelength from the short circuit when the sample is absent. When the sample is inserted in front of the short circuit, the minima shift toward the short circuit as shown in Fig.1. The shift of minimum is a measure of the dielectric constant. The signal that is lost in the form of heat in the dielectric causes a decrease in the standing – wave ratio. The decrease in standing – wave ratio is a measure of the loss tangent - $\mathrm{tg}\delta = \varepsilon''/\varepsilon'$.

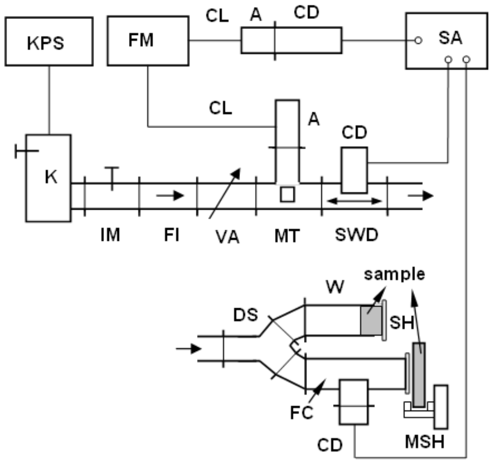

Fig. 2. *Experimental arrangement for dielectric constant and inhomogenities measurement,*
KPS –klystron power supply, IM- impedance match, VA – variable attenuator, MT – magic T, A – adapter, CL – coaxial line, FM – frequency meter, DS – directional switch, FI – ferrite isolator

The section of waveguide (W), (Fig.2) which was used to enclose the dielectric sample under test was connected to the slotted section (SWD) and the sample was formed to fit tightly into the waveguide. The measurement themselves were performed using the common attenuation measurement system as follows and the individual quantities are the same as in the Fig.1.

1. The empty waveguide section was terminated with the short circuit (SH) and measured the waveguide wavelength λ_g, which is given

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}}, \tag{1}$$

where λ is the wavelength in free space and λ_c cutoff wavelength (in our case λ_c= 45,72 mm).

2. The distance Δx using the “twice - minimum” method for high standing – wave ratio was measured. In this case (high SWR) the probe depth must be increased if a reading is to be obtained at a voltage minimum. This will, however, cause a) field deformation when the probe is at a voltage maximum and perhaps b) so much power on the crystal detector (CD) that it does not work in the square – low region. To avoid these problems we used this “twice – minimum” or “3 dB - method”, [1]. In this method we measured the distance between the points where the crystal detector output voltage was double the minimum (Fig.3.).

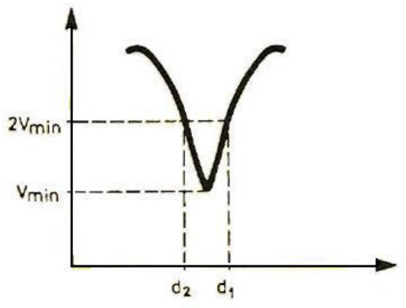

Fig.3. The “3 dB - method”

3. The position of the minimum (A) was recorded.
4. The dielectric sample of the length “d” was placed in the waveguide so that it was against the short circuit.
5. The distance Δx_s was measured by the “twice - minimum” method and the position of the minimum (B) was recorded.
6. The shift in the minimum Δl was recorded.
7. having these quantities it was possible to calculate

$$\frac{\mathrm{tg}\, x}{x} = \frac{\lambda_g}{2\pi d}\,\mathrm{tg}\frac{2\pi(\Delta l + d)}{\lambda_g}, \tag{2}$$

where the unknown x is multiple valued. Therefore it is necessary either to know the approximate value of the dielectric constant or to measure two samples of different lengths so that the correct value of unknown x can be chosen from the tables of $(\mathrm{tg}\, x)/x$.

8. The dielectric constant could be calculated from the formula

$$\varepsilon' = \left(\frac{x\lambda}{2\pi d}\right)^2 + \left(\frac{\lambda}{\lambda_c}\right)^2 . \tag{3}$$

9. The loss tangent could be calculated from the formula

$$\mathrm{tg}\delta = \frac{\Delta x_s - \Delta x}{\varepsilon' d}\left(\frac{\lambda}{\lambda_g}\right)^2 . \tag{4}$$

As it was mentioned above the primary task was to calculate ε' and $\mathrm{tg}\delta$ from (3) and (4). All needed quantities were measured for two dielectrics: pertinax and polyethylene (PET). These materials were chosen to verify the method comparing our results with the values from literature. For the reason mentioned above we used the method of two samples and measurements were carried out at frequency of 10GHz and the results are given in Tab.1

Tab. 1

material	ε'			$10^4 \cdot \mathrm{tg}\,\delta$		
	our results		from literature	our results		from literature
	shorter sample	longer sample		shorter sample	longer sample	
pertinax	5.3	5.6	$4 \div 6$	240	210	800
PET	2.97	2.90	2.26	5	10	3.6

The evaluation after Tab.1 will be restricted to the comparison of our measurement results obtained from the samples of different lengths with the values accessible from literature. It is not possible to attach essential significance to the differences between literature and our values for ε' because descriptions of their chemical structure are not available.

The differences from the samples prepared from one piece of material are more significant. At the measurement of ε' the differences are acceptable (literary information admit for $\varepsilon' \pm 10\,\%$ variation acceptable for practice and for $\mathrm{tg}\,\delta \pm 20\,\%$). The differences in our measured values of $\mathrm{tg}\,\delta$ could occur from the following reasons:

The values Δx and Δx_s, after Fig.1, are being measured by this method hardly. The reason of difficulty lies in the following. The reading of the probe position on the measuring line is relatively precise (the line is equipped with vernier) but the probe setting with low loss materials (polyethylene) is very hardly realized because the positions at free waveguide and with low loss dielectric differ inappreciably.

This immediately led us to the orientation in ε' and $\mathrm{tg}\,\delta$ measurement by help of cavity resonators. Using this method we can avoid standing wave measurement by help of measuring probe and the measurement will be realized through frequency and Q of cavity measurement. We have already manufactured such resonator in figure of cylinder cavity, and its first qualitative judgment of its applicability for this intention was made. The resonator was touched with a transmitting loop to the microwave source (K) and the reflected signal was scanned by the ferrite circulator (FC). As testing probes we used bar shaped samples from pertinax, teflon, wood and metal. The cavity reaction to the sample presence represented up to 80 % change of the reflected signal depending on the sample sort (of course on the sample position as well).

After having managed the means for judgement of the characteristics for plastic we could proceed to the following issue that is to carry out the measurements on plastics with defined inhomogenities. For this reason the same microwave signal source was used but without the measuring line. Instead of it there was connected a ferrite circulator in the same arrangement as it was mentioned at cavity resonator measurements. But in this case the ferrite circulator was terminated with an iris (short circuit provided with a rectangular ablong slot). The slot shaped iris was used to radiate microwave energy into the device under test. It reflected a part of the signal which was received by the iris and though the circulator fed into one of its three ports (equipped with detector) and into the selective amplifier (SA). The frequency used was the same as in the previous case (10 GHz) Absolute value and phase of this signal correspond to those of the reflected microwave signal from the sample. Therefore, it directly depends on the geometry of the device under test and the distribution of the dielectric constant (ε'). Therefore, in regions with pores ($\varepsilon' = 1$) and in regions without pores or other defects ($\varepsilon' \rangle 1$) the reflection coefficients will be different.

These measurements were carried out on the pertinax samples. The sample was fastened on a movable holder (MSH) and the shift was realized by means of precise double screw thread without backlash and the position was read from the measure.

Cylindrical holes and longitudinal slot shaped depressions were digged up into pertinax sample as defined non-uniformities. Almost all measurements have showed on the same shape and the typical ones are in the Fig.4, 5, and 6. In all figures the reading on selective amplifier signal dependences from the positions of the hole (Fig.4) and slots (Fig.5, 6) in front of the iris are plotted.

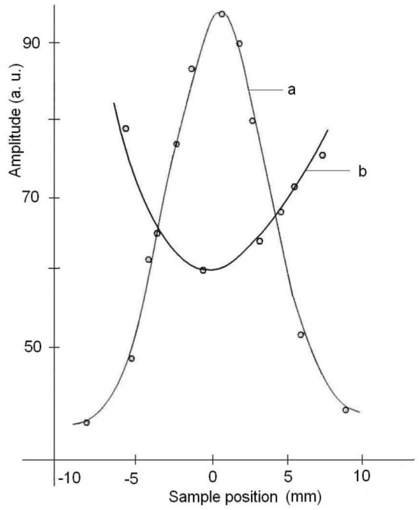

Fig. 4. Dependence of refracted signal on the hole position, a) open, b) covered side

Fig.4 represents pertinax sample measurements with the cylindrical hole of diameter of 9.8mm and the depth of 8mm (the plate thickness was 10mm).

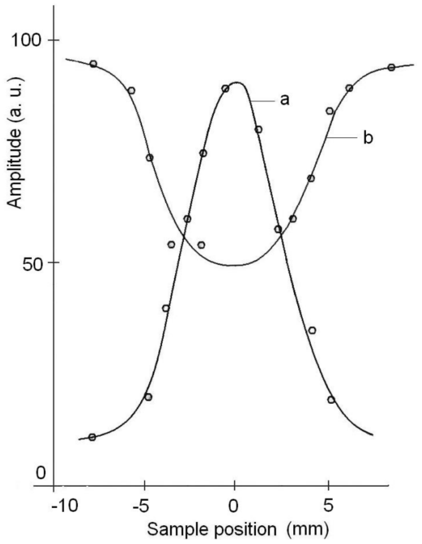

Fig. 5. Dependence of refracted signal on the slot (with – 4.5mm) position, a) open, b) covered side

There are plotted results of longitudinal slots measurements in Fig.5, 6. The slots of length of 40mm and maximum depth of 8mm, width of 4.5 and 1.5mm respectively were cut by circular saws.

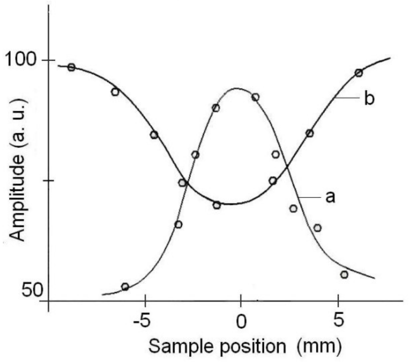

Fig. 6. Dependence of refracted signal on the slot (width - 1.5mm) position, a) open, b) covered side

Measurements from the open side are marked in the Fig.5 and 6 with the letter "a" and the measurements from the opposite side with the letter "b".

Often it occurs in material engineering practice the problem to find out metal impurities in dielectric plates. For this reason we placed on our agenda an experiment according to which it could be possible to confirm such possibility by microwaves. For this purpose a hole (diameter of 7mm, depth of 6mm) was bored into the teflon plate (thickness of 8mm) and sawdust was put in. This hole was pasted over with a transparent foil. Such adapted it was exposed to the microwave signal transmitted from the open waveguide and the reflected signal was observed. The results are in the Fig.7.

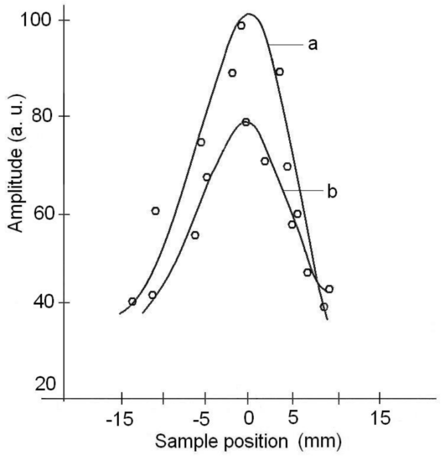

Fig. 7 Dependence of refracted signal on the hole position, a) open, b) covered side

The letters "a" and "b" are of the same meaning as in the previous figures. It is evident from this experiment that microwave method is applicable also for this purpose.

3. CONCLUSION

Some literary information [2] but refer that at certain applications combinations more methods at NDT are required and on the contrary it is only rarely possible to apply one method on more materials. Just this was one from the facts, which introduced us to the orientation on microwaves. The performed measurements demonstrate a practicability of microwaves in supposed applications and besides we give the experimental proof about their use at an identification of foreign matters or non-desired impurities.

Next we will pay our attention to cavity resonators for the sensitivity and accuracy increase at same applications and father to defects identification.

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