electroscope

Application of short circuit waveguide method for evaluation of inhomogenities in dielectric sample

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Abstract:
In the paper main consideration is paid to investigation of inhomogenities in dielectric sample from the standpoint of their impedance properties and reflected signal amplitude. Such application include inspecting modern materials such as composites, detecting and characterizing surface and volume flaws, and evaluating the compressive strength of cement structures.The paper deals with measurement of reflex coefficient in dependence on crack depth on dielectric samples on microwave frequencies from the X – band. Evaluations are made by means of quantities used in microwave technique. Obtained quantities are compared with each other and also with analogous to the quantities measured at the same conditions on metal sample.

INTRODUCTION

In the broad spectrum of material testing methods as far as their duration of application, microwave technique plays in spite of its already proven possibilities relatively a new approach to these problems. For possible cause of this state a poor understanding of the microwave theory and practice in the non-destructive testing community is considered. However many published experiences prove broad possibilities of this method and new accesses to this problems as well as new technical possibilities make the microwave testing easily accessible. Besides that the capability of providing real-time information, makes this method suitable for on-line industrial applications.

In view of dielectric material properties and the capability of microwave signals to penetrate inside dielectric media easily the microwave testing has asserted itself in this area naturally first. In addition to that this method has asserted itself at cracks detection on metal surface and not only at finding them out but also at determining their properties. Among these also our publication concerning crack depth detection can be included, [1].

In this connection a question appeared if it is possible to detect a crack depth in dielectric materials. For this purpose we chose some dielectric materials, from which we made samples with defined measurements and with an artificial changeable crack depth.

The microwave signal response depends on the dielectric properties of the material and which are characterized by a macroscopic quantity the complex permittivity. The measurement of this quantity represents a special technique and there are many papers concerned with these problems and also we have devoted ourselves to it, [1].

The subject of this paper is to take a stand on the possibility of investigation of defect in dielectric materials and in the some way as it was used on metals, [2], [3].

WAVEGUIDE METHOD FOR MEASURED VALUES PROCESSING

As this paper is of experimental character we will mention only relations and formulae concerning the quantities in question. Our experiments are directed on the load complex impedance, $\dot{Z}$ measurement. This impedance is represented by a dielectric sample with crack, which is put at the end of the microwave line. The quantity which enables to compute the impedance is the complex reflection coefficient, $\dot{\rho}$ and it can be obtained from the standing wave ratio (SWR). The reflection coefficient can be expressed by means of the electric component of the incident, E^+ and the reflected, E^- electromagnetic waves.

$$|\rho| = \frac{E^-}{E^+} . \qquad (1)$$

Taking the wave character of the electromagnetic wave into consideration we can write

$$\dot{\rho} = |\dot{\rho}_0| \mathrm{e}^{\mathrm{j}(\varphi_0 + 2\beta z)}, \qquad (2)$$

where $\dot{\rho}_0$ is the value of $\dot{\rho}$ at the beginning of the line, φ_0 is initial phase of the $\dot{\rho}_0$, $\beta = \frac{2\pi}{\lambda_g}$ is the phase constant and λ_g is the wavelength in the waveguide and z is the distance from the beginning.

Since the reflected wave interferes with the incident wave, there will be a standing wave pattern in the space between material and detecting probe inside the waveguide and it is given

$$s = \left| \frac{E_{\min}}{E_{\max}} \right|. \qquad (3)$$

Taking into consideration (1), the relation between s and $|\dot{\rho}|$ we can write

$$|\dot{\rho}| = \frac{1-s}{1+s}. \qquad (4)$$

By means of relations between incident and reflected waves we can express the impedance in the complex form as

$$\dot{Z} = Z_0 \frac{1+\dot{\rho}}{1-\dot{\rho}}, \qquad (5)$$

where Z_0 can be computed from the characteristic impedance of the free space $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$, used wavelength and the critical wavelength for used waveguide.

Finally the relation which makes the calculation of complex impedance, $\dot{Z}$ possible is, [4]

$$\dot{Z} = Z_0 \frac{1-|\rho|^2}{1+|\rho|^2 - 2|\rho|\cos\varphi} + \mathrm{j}Z_0 \frac{2|\rho|\sin\varphi}{1+|\rho|^2 - 2|\rho|\cos\varphi}, \qquad (6)$$

where $\varphi = 2\beta d_{\min} - \pi$ is the phase angle of $\dot{\rho}$, $d_{\min}$ is the distance of the first minimum of electromagnetic wave from the load. Because s and $d_{\min}$ are directly measurable on the microwave slotted line and in the similar way λ_g can be determined, complex impedance of the investigated sample can be from (6) calculated.

EXPERIMENTAL RESULTS

The experiments were carried out on the standard laboratory equipment, [5] in the connection depicted schematically in Fig. 1.

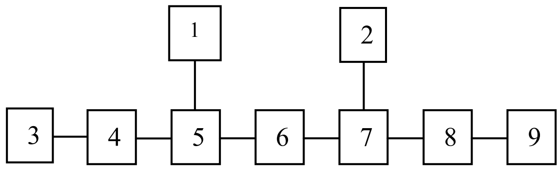

Fig. 1: Experimental set up for impedance measurement: 1 – wavemeter, 2– selective amplifier, 3 – microwave source, 4 – ferrite insulator, 5 – directional coupler, 6 – calibrated attenuator, 7 – slotted line, 8 – measured sample, 9 – depth gauge

As a source of microwave signal was used microwave signal generator and the measurements were carried out on frequencies from the X - band on the transversal electric wave TE_{10} and the measured quantities were detected by the selective amplifier. As a measuring method was used the method of “open waveguide”. The artificial crack depth was adjusted by a precise equipment and measured by the depth gauge. The depth of crack was positioned from 0 mm to 20 mm and at every adjusted crack depth there was measured SWR. The measurements were performed on three different dielectric samples and for comparison one measurement on a metal sample was made, too.

All samples were measured on frequency 10 GHz and polyurethane and pertinax samples also on frequency 7.86 GHz. All measuring results with respective data are in the relevant graphs.

The quantities, we are interested in were calculated from the formulae (3), (4) and (6). The individual courses are divided in five graphs because of making the overview easier.

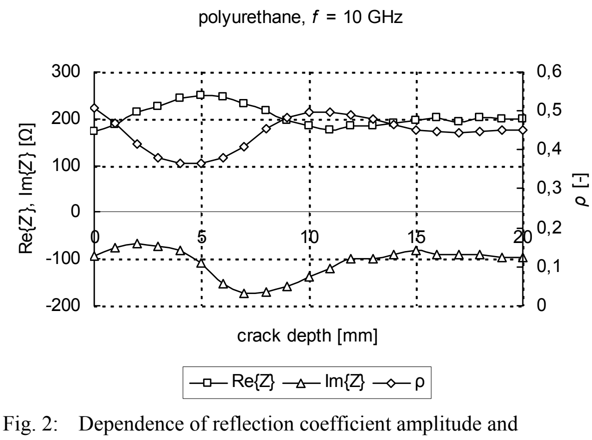

Fig. 2: Dependence of reflection coefficient amplitude and impedance on crack depth for on f = 10 GHz

In Fig. 2 there are plotted dependences concerning $|\dot{\rho}|$, real and imaginary part of complex impedance of polyurethane on frequency 10 GHz.

Because $|\dot{\rho}|$ and imaginary part of complex impedance have the similar courses for comparison of all three samples in Fig. 3 we state only courses of $|\dot{\rho}|$.

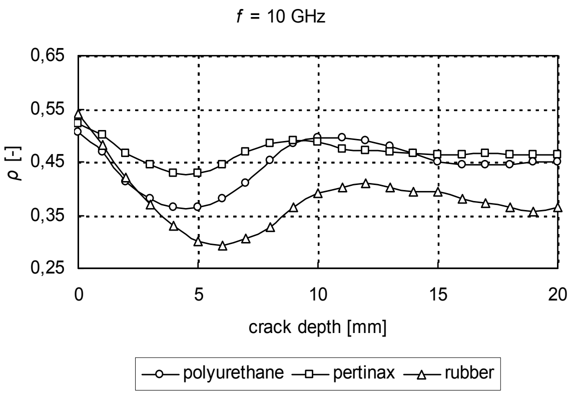

Fig. 3: Dependence of reflection coefficient on crack depth for polyurethane pertinax and rubber on f = 10 GHz

In Fig. 4 there are plotted courses for $|\dot{\rho}|$ and real part of complex impedance and there are plotted dependences of pertinax and rubber (again for the better overview).

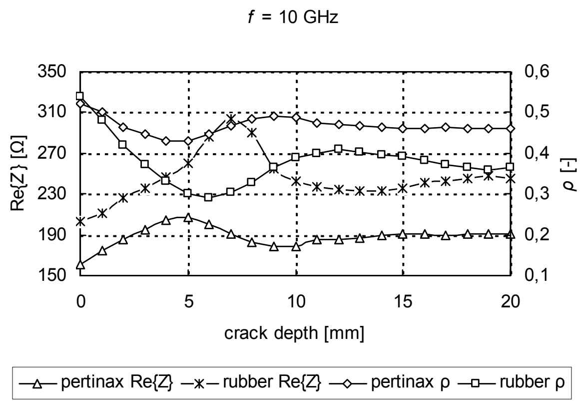

Fig. 4: Dependence of reflection coefficient amplitude and real part of complex impedance for pertinax and rubber on f = 10 GHz

The courses on frequency 7.85 GHz are plotted for $|\dot{\rho}|$ and real part of complex impedance in Fig. 5.

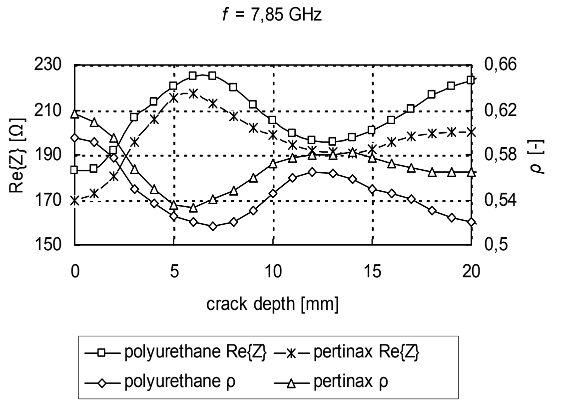

Fig. 5: Dependence of reflection coefficient amplitude and real part of complex impedance for polyurethane and pertinax on f = 7,85 GHz

From the obtained values of SWR and standing wave minima position the complex impedance values were computed, [2]. The dependence of investigated defect complex impedance absolute value on the probe position is in Fig. 6.

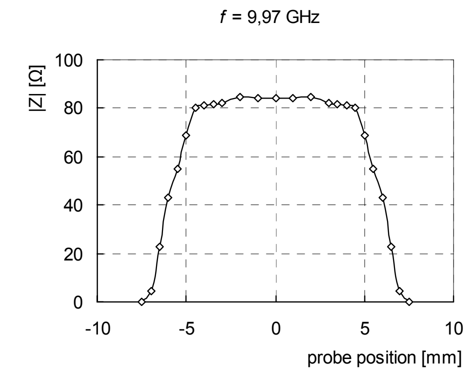

Fig. 6: Dependence of the defect impedance absolute value on the probe position on f = 9,97 GHz

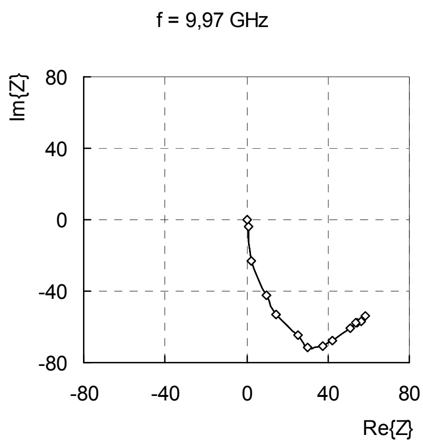

Fig. 7: Dependence of the impedance phase on the probe position in the complex plane on f = 9,97 GHz

It has been found out, that not only the reflected signal amplitude is changed but also the phase of investigated defect impedance. The results for the reflected signal phase changing are plotted in the complex plane, Fig. 7.

It can be concluded (Fig. 6,7) that it is possible to find the defect in dielectric sample with open waveguide probe and using the information about amplitude and phase of complex impedance changing to estimate the geometric properties of the defect in dielectric sample.

Another approach to estimation of defect is calculation of complex reflection coefficient $\dot{\rho}$ of electromagnetic wave in waveguide from measured data, [3].

In case of need of defect measurement from different probe distances (liftoff) from pertinax sample we have completed this phenomenon of phase influence on the course of the reflected signal with a continuous measurements of probe distance from the investigated defect. The results are shown in Fig. 8 for pertinax sample from the open (OD) and closed side (ID).

In Fig. 8 can be seen, that with increasing the open waveguide probe distance from the investigated plate the phase of reflected signal is changed periodically and the amplitude of reflected signal is decreasing.

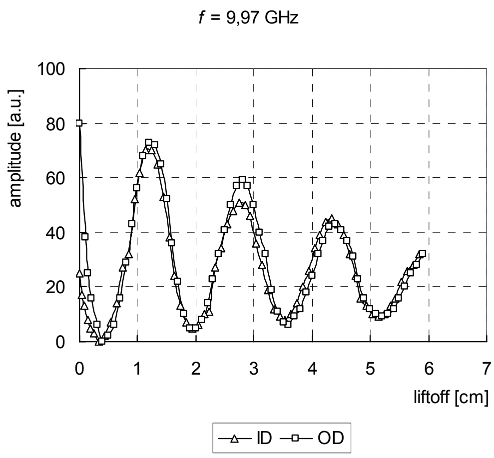

Fig. 8: Dependence of the reflected signal amplitude on the probe distance from the open and closed side

CONCLUSION

The purpose of this work was to find out to what extent the knowledge of dependence of impedance on the crack depth observed by means of microwave frequencies on metal can be used for dielectric materials. Primary quantity usable for this assessment was the reflection coefficient obtained immediately from the SWR measurement. The measured and calculated results are given in the graphic form and are compared each other in common graphs which provide a good overview about basic quantities and simultaneously give an initiative for orientation on practical applications. As there were used samples with different dielectric constant it can be seen from all graphs the influence of dielectric properties on the resolution of defect observation by microwave signal. From this point of view the figure with another frequency (7.85 GHz) gives an image for comparison of microwave signal resolution for used frequency.

It follows from this paper that the possibility of utilization of microwave frequencies for discovering defects that way as it is used for metals, [4], [5] is feasible also for dielectric materials and knowledge stated in it can help at determination of conditions and requirements for the particular applications.

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