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SOME METHODS OF MICROWAVE APPLICATION IN NONDESTRUCTIVE TESTING

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ABSTRACT

Information bout the possibilities of microwave techniques are given in the paper. The paper is aimed at practical applications and for theoretical data references to relevant literature sources are indicated.

KEYWORDS: nondestructive testing, microwaves, defect, waveguides

INTRODUCTION

Nondestructive testing (NDT) performs each time more important function in different areas of modern society. NDT is important from the point of safe running in various areas of economy as above all aircraft industry, operation of nuclear reactor, gas and oil transportation, areas of automobile and machine industry and at present these methods find each time bigger application in the medicine area, [1]. The aim of NDT is to find out and define anomalies which occur in the investigated material without damaging it. This way of testing minimizes the number of breakdowns, which are connected with hidden material damages. NDT makes possible not only to detect hidden damages but it is suitable also for the monitoring of inhomogenities growing till the moment when they may acquire critical dimensions at the present NDT methods have overspread also in on-line control. This way it is possible to reach the information above the condition and quality of products in the real time and also greater fluency of the production. Information, which are the result of NDT in the real time are used not only as a way out for the closing product sorting but also as a feedback information for the correct machinery setting in the production line.

For NDT of materials many physical principles are used as e.g. mechanical, acoustic, thermal, electromagnetic, optical. Every of these principles has some advantages and is suitable for certain area of nondestructive control.

This paper deals with the experimental verification of the possibility microwave signal using for inhomogenities and defects testing, namely of metal materials.

MICROWAVE APPROACH

It is perhaps curious that a technique as developed as microwave testing has been given only scant attention as a method for nondestructive testing of materials. This is particularly so since much of existing work with microwaves is directly applicable to NDT. In fact, microwave techniques have been used in a large number of applications that can be classified as nondestructive testing applications ranging from large scale remote sensing to detection of tumors in the body, [1]. The instrumentation is also easily available and, unlike for other methods of NDT, requires little modification. Perhaps the main reason for this state is the fact that the resolution one can expect of microwave testing is of the order about half a wavelength which, with standard microwave equipment, is of the order of at most 1mm (at 100 GHz the wavelength is 3mm). We have devoted ourselves to this fact and have achieved more precise resolutions at cracks investigations. Other reasons are that microwave measurements are viewed as noisy and "difficult" to perform. Current instrumentation is excellent, computer controlled, and with excellent noise figures.

Applications of microwaves to NDT of materials date back to at least to early 1950's. In spite of that their application has domesticated at plastics, paper industry as well as composite materials. More detailed enumeration of microwave using in industry provides the publication of Nondestructive Laboratory, University of Missouri – Rolla, [2], [3].

EXPERIMENTAL ACCESS

Our attention was aimed namely at the testing of metal materials. On the first sight it was little probable that, for example with a probe made from a open waveguide, it could be possible explicitly to find a defect which represents only a tiny fraction of the conducting surface radiated with the microwave signal from the reflected part of this signal. But after realizing that the defect can be considered as a terminated impedance of such probe (open waveguide), we can get information about the character of this impedance (that is about the defect complex impedance character). For the better "contact" with the directly measurable quantity we present only an example of standing wave ratio ($\mathrm{SWR} = \frac{E_{\min}}{E_{\max}}$, $E_{\min}$ and $E_{\max}$ are electric intensity maximum and minimum, respectively, [1]) measurement in dependence on the defect depth. The relation between SWR and the reflection coefficient and subsequently complex impedance give a similar dependence, where complex impedance is the terminating impedance of the waveguide, in our case of the defect as a waveguide section.

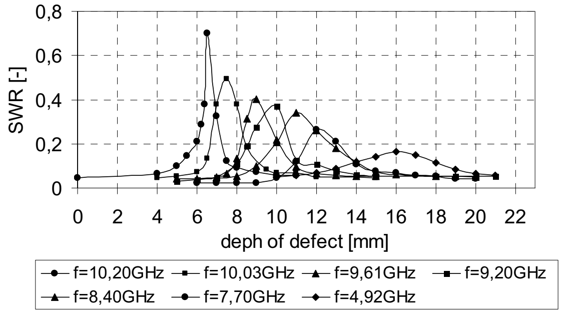


Fig. 1 Dependence of SWR on the defect depth for seven frequencies

Thereafter the impedance of the investigated defect in this way depends directly from the distance of the short – circuit of the connected section under the probe (in our case from the defect depth) and so measured SWR values plotted in dependence from the defect depth already correspond with this relation, Fig. 1. Quasiresonant courses for individual frequencies correspond to the theoretical assumption and show that the particular samples with different defect depths behave at particular frequencies as a quarter-wave transformers.

In this connection it will be in place to become aware of the fact that these quasiresonant courses can cause not unequivocal determination of the defect depth

EXPERIMENTS FOR USE IN PRACTICE

We have used a standard microwave apparatus at our measurements, Fig. 2 and the majority of measurements were carried out with the open waveguide method serving as a measuring probe. The experiments were performed at frequencies from the X – band (8-12 GHz), except for one case - 5 GHz - at monitoring the frequency dependence on the defect depth.

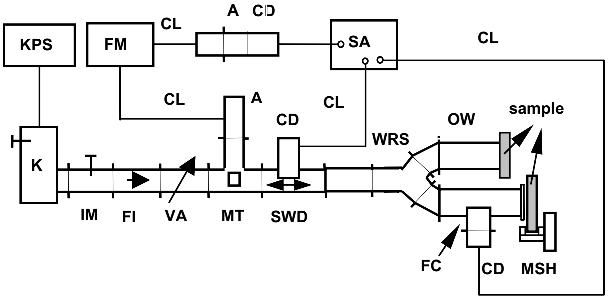


Fig. 2 Experimental set up for inhomogenities measurement, K – reflex klystron, KPS – klystron power supply, IM- impedance match, VA – variable attenuator, MT – magic T, A – adapter, FM – frequency meter, FI – ferrite isolator, CL – coaxial line, FM – frequency meter, WRS – waveguide rotation change–over switch, SWD – standing wave ratio measurement line, FC – ferrite circulator, CD – crystal detector, OW – open waveguide, SA – selective amplifier, MSH – movable sample holder

The basic pieces of knowledge were the measurements aimed at the influence of the defect depth on the reflected signal amplitude. For this purpose two measurements for comparison were carried out:

1. measurement of the reflected signal on a lossless waveguide,
2. measurement of the reflected signal on a sample with the defect.

The reflected signal was in both cases recorded through the ferrite circulator and the measurements were performed for such short-lime piston positions on the lossless waveguide which corresponded to the respective defect depth. The comparison of the both measurements is in the Fig. 3.

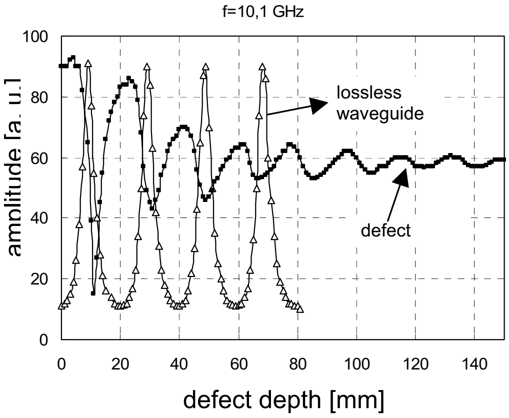


Fig. 3 Dependence of reflected signal amplitude from the defect depth in metal and from the position of the shorted-line piston in lossless waveguide

One can concesive of the decreasing amplitude of the reflected signal at the defect depth settling at $(2n+1)\frac{\lambda_g}{4}$, ($\lambda_g$ is length of wave in waveguide and n is integral number), distant maxima and consequently also about up to what depths the reliable information about the defect with particular material properties can be obtained at the given measurement precision.

After verifying our theoretical assumptions, [4] we proposed two new methods for the defect evaluation and have also tested them. The first method is based on a special microwave line connection using the balancing principle with the magic T as a passive element from microwave technique with wide possibilities. We will recapitulate only its properties from the point of view of our measurement. Magic T, Fig. 4, is symmetrical with regard to the plane crossing through the axes of the ports C and D. Microwave generator will be connected to the port C and the indicator to the port D. If the ports A and B are loaded with equal loads, then the energy from generator is divided in port A and B and in the port D energy does not show.

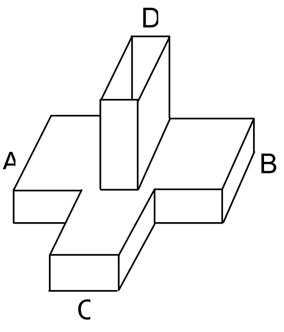


Fig. 4 Magic T

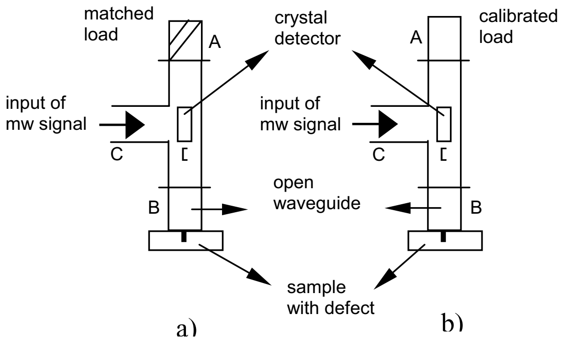


Fig. 5 Magic T connection for the defect depth measurement

If the ports A and B are not the same, then a part of energy in consequence of non symmetry in the fields gets into D and the reading on the indicator will depend from the degree of the load difference in ports A and B. The same is valid when the signals are reflected from loads in ports A and B. We have made use of these properties in two ways:

a) for obtaining similar information about the defect as at classical measurements,
b) for obtaining direct information about the defect depth.

The measurements were performed in the connection illustrated in Fig.5.

In the case according to Fig.5a with the matched load in the port A and the indicator in the port D, the signal indicated in the port D will be proportional to the reflection coefficient from the port B. This way in our measurement port B was terminated with the open-waveguide probe and the sample with a defect (width 0,5 mm, depth 8,5 mm) was shifted in front of it. Corresponding graph is plotted in the Fig.6, curve a.

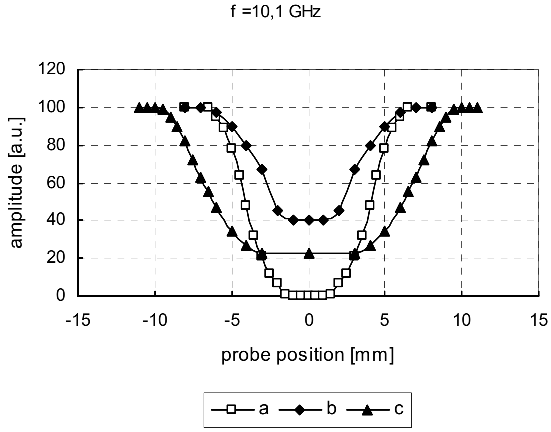


Fig. 6 Dependence of reflected signal amplitude from the defect

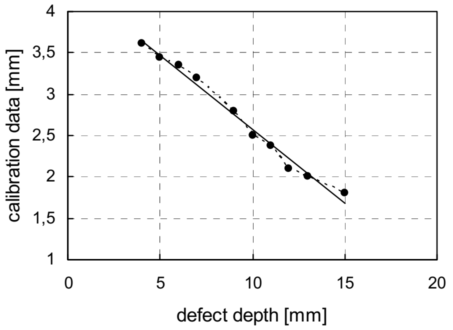


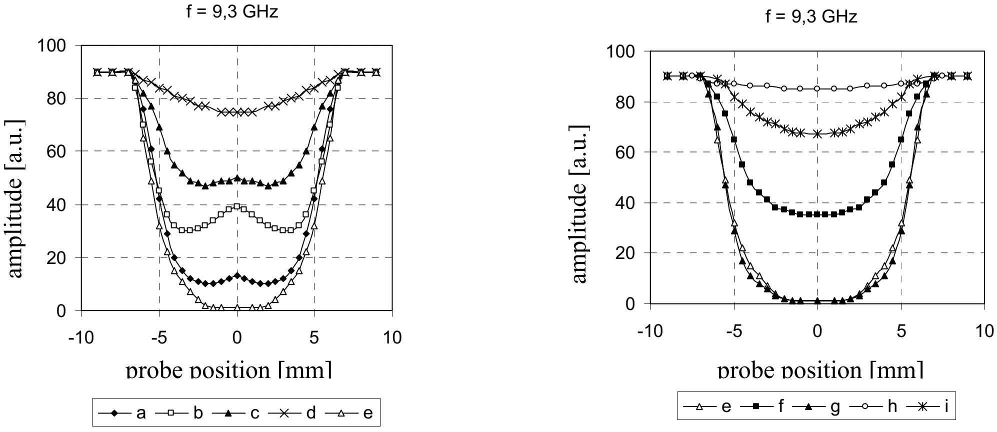
Fig. 7 Calibration curve for from magic T

Measurement in connection according to Fig.5b was performed for the purpose of getting a facility for simple measuring of the crack depth. To the port A was connected an artificial defect simulating the real one with the continuously changing depth. To the port B were gradually attached samples with known depths and for each depth the bridge was balanced (port D without signal) and corresponding reading recorded. This way the calibration was obtained and it is plotted in the Fig. 7, (dotted line – measured, full line – idealized).

Among other things we were interested in the possibility cavity resonator using for the examination of defects in metal samples. For this purpose we have used our experiences with cavity resonators, [4] where also basic theoretical information are presented. We supposed that at suitable resonator binding on the defect as an impedance element it will influence the resonator's quality factor Q and its resonant frequency.

For this purpose we have carried out an experiment with the resonator connected on standard microwave line. The resonator was connected on standard microwave line in the transmission way and one resonator aperture was terminated with an open waveguide probe. Resonator was tuned in resonance. In front of the probe was shifted a metal sample with the defect (width 0,5mm, depth 8,5mm). The behavior of the resonator was followed by means of a signal brought out through a loop antenna. The measured values are plotted in the Fig.6, curve b. We have plotted in Fig.6 for comparison also the curve c obtained by previous familiar way (through the ferrite circulator).

At defects detection it is necessary to admit that an older crack is partly or wholly filled with rust or another deposit and also can be covered with paint, rust or with their combination. Additional crack filling can also be water or various water solutions. These materials signify from the microwave defectoscopy point of view dielectrics which will have an influence on the defect viewed as a part of the microwave network. We followed these conditions experimentally and the obtained results are in Fig. 8.



a) b)

Fig. 8 a) Dependence of reflected signal amplitude from defect gradually filled with the rust layers (a – one layer, b – two layers, c – three layers, d – defect filled with rust, e – empty defect), b) Dependence of reflected signal amplitude form the presence different dielectrics in the volume and on the defect surface

In the Fig. 8 there are demonstrated courses of the reflected signal from the defect gradually being filled with rust layers (the thickness from 0,3mm in the width of 1mm). In the Fig. 8 we also present for a comparison the curve of the reflected signal course from the empty crack (curve "e"). The curve "f" represents the course of the reflected signal from the defect filled with pertinax (for the sake of the different dielectric constant), the curve "g" represent the reflected signal from the empty defect covered with a paint, the curve "h" from the defect filled with water and the curve "i" from the defect filled with paint. For every mentioned filling the complex permittivity was measured by suitable measuring method, [1].

CONCLUSIONS

Our work was directed towards microwave technique utilization through nontraditional way and we have paid our attention primarily to the experimental verifying of microwave utilizing for defects in metals. Cracks were tested from the point of view the waveguide techniques and on this base we could characterize it as special waveguide section and under certain conditions the defect can manifest itself as a quarter – waveguide transformer. This property allows to detect it as a quasiresonant effect and from finding this out we could state what frequencies appertain to the individual defect depths. Finally we can state that microwaves can be used for finding out crack presence, its depth, width, and orientation and in cooperation with other method, [4] they can be used as effective tool for material testing.

Our goal was to find an interface of practical testing knowledge with the theory which is at disposal in microwave domain. With the intention of obtaining an implement not only for the detection of the defect but also for its quantitative evaluation.

The acquired experiences can be summarized in several points indicating possibilities of microwave NDT:

1. to find out the defect (with a waveguide or a coaxial probe),
2. to determine the defect orientation, [4]
3. to obtain information about the defect width, [4]
4. to determine the defect depth (according to the defect impedance), [4],
5. to fix the defect depth utilizing the quarter-wave transformer effect and the attenuating characteristics.

It is worth also saying that microwaves offer additional possibilities, with regard to expanding their utilization as well sensibility and accuracy. These goals can be achieved by using higher frequencies (around 100 GHz) and more sophisticated techniques (e.g. cavity resonators).

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