Microwave Based Non-Destructive Testing using Modified Eddy Current Systems

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Abstract. Microwave-based non-destructive testing has proven to be powerful for the defectoscopy of parts made from plastic or fibre-reinforced plastic. This paper describes a transverter to be used together with standard eddy current systems, which makes them applicable also for microwave-based defectoscopy. The test results represent themselves similar to those of eddy current tests. This combined instrument makes it easy for the inspector to make use of the new microwave-based non-destructive testing. As an example a polypropylene plate with flat bottom holes is inspected using this principle and results are shown: The defect signatures have features, which enable the inspector to distinguish between geometrical size of the defect and its depth below the surface.

Introduction

In feasibility studies the microwave-based non-destructive testing (NDT) has proven to be powerful, especially for the defectoscopy of parts made from plastic and fibre-reinforced plastic [1], [2], [3]. For weight reduction purposes such materials are more and more used in the fields of automotive, aerospace, and ship building or even windpower. Up to now, however, microwave defectoscopy represents itself more as an academic research topic than a routine procedure for practical applications. The reasons for this are probably that the microwave technique and the interpretation of the test results seem to be complicated. The present paper solves these problems by proposing an appropriate transverter for use together with standard eddy current test systems. This makes it easy for the experienced inspector to use microwave-based NDT, and, furthermore, the test results represent themselves quite similar to those in the well-known eddy current testing. The following paragraphs will show these principles.

1. Measurement setup

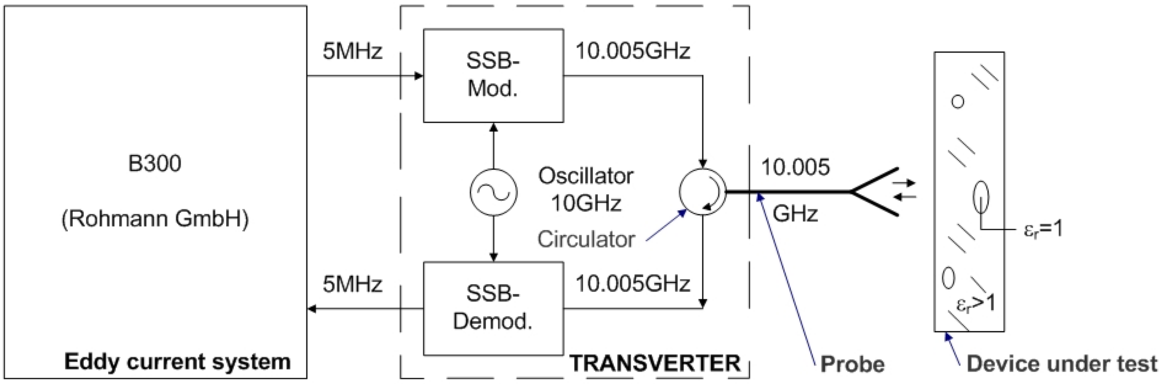
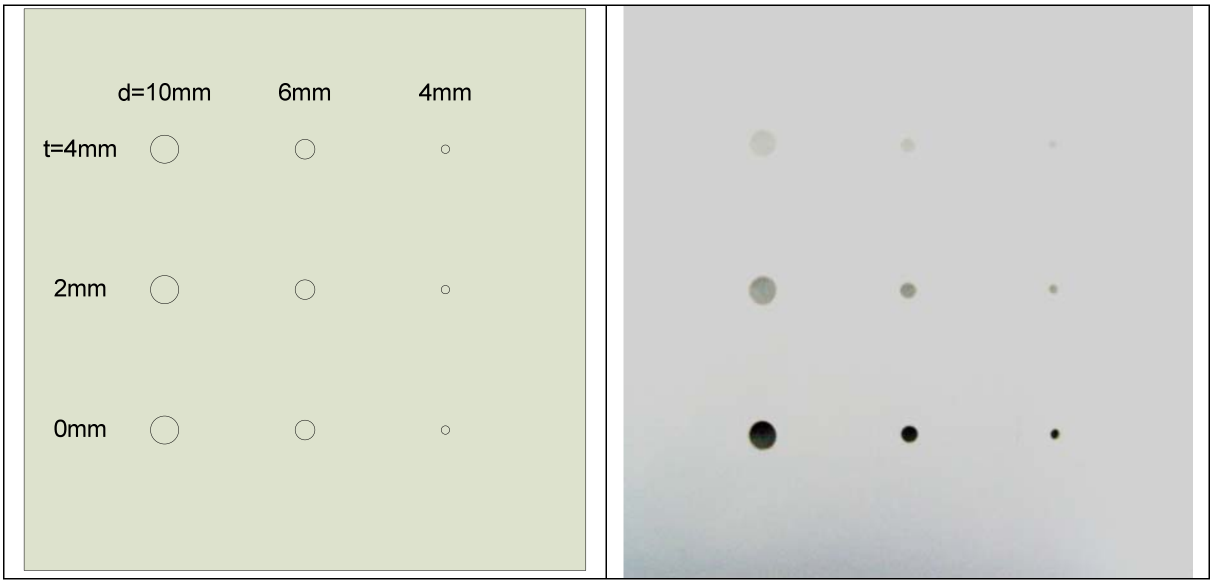


Figure 1: Block diagram of test system consisting of conventional eddy current system, transverter and probe. Added is the device under test.

Fig. 1 shows the principle of the setup. It consists first of a conventional eddy current test set, here a B300 from Rohman GmbH is used. The eddy current system is adjusted to operate at 5 MHz. The transmitter signal is transformed to 10 GHz by using a 10 GHz oszillator and a single-sideband modulator (SSB-Mod.). By using a circulator, which transfers signals only in arrow direction from one port to another port, the probe is fed. The probe consists of a microwave tuner and iris at the end of a rectangular waveguide. The waveguide dimensions are 22.86 mm x 10.16 mm (X-band). By using slot shaped irises with various apertures like 10.0 mm x 1.0 mm or 10.0 mm x 5.0 mm the desired local resolution can be realised. By this microwave probe the 10.005 GHz signal is guided into the device under test. The microwave tuner is adjusted such that reflections in defect free regions are compensated which results in the total reflection coefficient being zero. Signals reflected by discontinuities are taken up by the probe and passing the circulator supplied to the single sideband demodulator (SSB-Demod.). Because modulator and demodulator are fed by the same 10 GHz oscillator, the 5 MHz output signal of the SSB-demodulator refers to the 5 MHz input signal in amplitude and phase. By using the SSB output signal as input for the eddy current system this conventional system can be used to process the signal. The input signal contains the amplitude and the phase information of the microwave signal reflected by the device under test. It depends directly on the geometry of the device under test and the local dielectric constant in it. The mentioned microwave tuner in the probe is adjusted such that at a defect free region of the device under test the reflected microwave signal and even the 5 MHz receiver signal result to zero. For this situation the eddy current system is balanced , i. e. adjusted to the origin of the complex plane (x-y-plane). Phase shift should be adjusted such that liftoff changes cause deflections in x-direction. Defects represent themselves as deflections out of the origin.

2. Measurement results

Figure 2 shows a used polypropylene (PP) plate with flat bottom holes (FBH). The dielectric constant is in the region 2.2 ... 2.6 [4]. Figure 3 shows the measured signatures of the FBH within the 10 mm thick PP plate, measured from the covered side. The nine single plots are the signatures of the defects, displayed in the complex plane of the reflection coefficient. This is very similar to the eddy current testing, where the impedance is displayed in its complex plane. In each single plot of figure 3 the origin r=0 is located in the centre of the grid.



a) b)

Figure 2: Polypropylene (PP) plate with flat bottom holes (FBH). Diameter d=4 mm, 6 mm, 10 mm. Depth or residual wall thickness of the flat bottom holes t=4 mm, 2 mm, 0 mm (through hole). View from the open side. Plate thickness 10 mm. a) principle distribution of FBH, b) photograph of the plate.

The signatures are generated by moving the device under test under the probe from a defect free position across a defect to the next defect free position. The chosen iris aperture was 3 mm by 10mm. The long side of the aperture was perpendicular to the moving direction. As described in paragraph 2 the microwave tuner was adjusted such that r = 0 over defect free positions. Therefore, all signatures begin and end at $r \simeq 0$. Slight deviations from the origin r = 0 are caused by liftoff changes. When crossing the defects a curve is generated, which under a certain angle reaches a point with maximum distance from the origin. Comparing the single plots of the horizontal rows in figure 3 shows that the maximum distance is a measure for the geometrical size of the defect. Comparing the single plots of the vertical columns shows that the angle of this point is a measure for the depth of the defect, which is equal to the residual wall thickness of the FBH. Figure 4 summarises the results. Although only nine defects are tested, the systematic behaviour can clearly be recognised. Therefore, the dependencies are supplemented by a grid. So, figure 4 has lines of constant diameter d and lines of constant residual wall thickness t. These lines are almost perpendicular to each other. On principle they are spirals around the origin and straight lines through the origin, respectively. Using this diagram the inspector can evaluate the depth of the defect and its geometrical size from the signature. This type of procedure is similar to that in eddy current testing, when a distinction is to be made between cracks and magnetic inclusions [5].

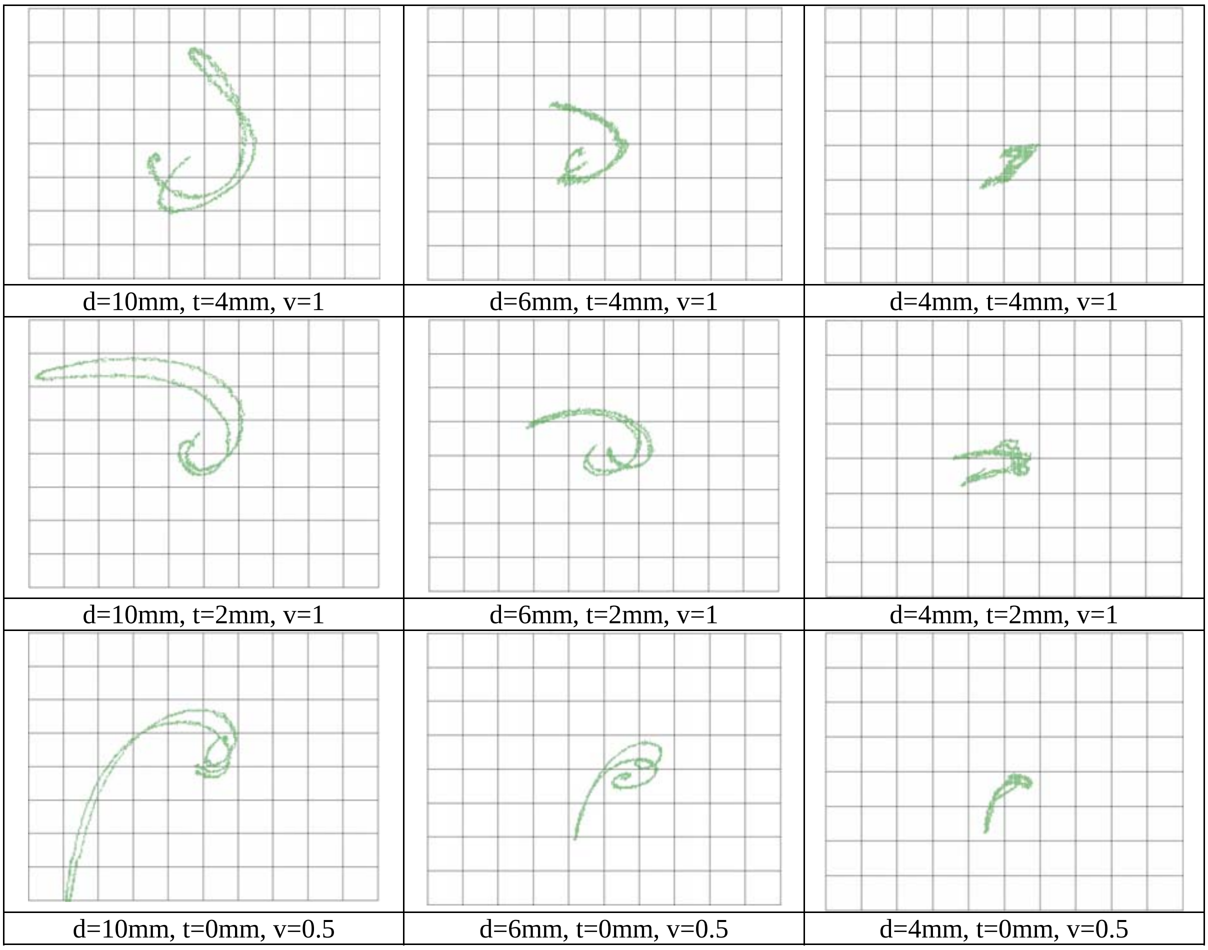


Figure 3: Measured signatures of flat bottom holes from the covered side. From left to right: diameter d= 10 mm, 6 mm, 4 mm. From top to bottom: residual wall thickness t= 4 mm, 2 mm, 0 mm (through hole). Signal amplification v=0.5 in the bottom row, otherwise v=1. Plate: polypropylene, 10 mm thick.

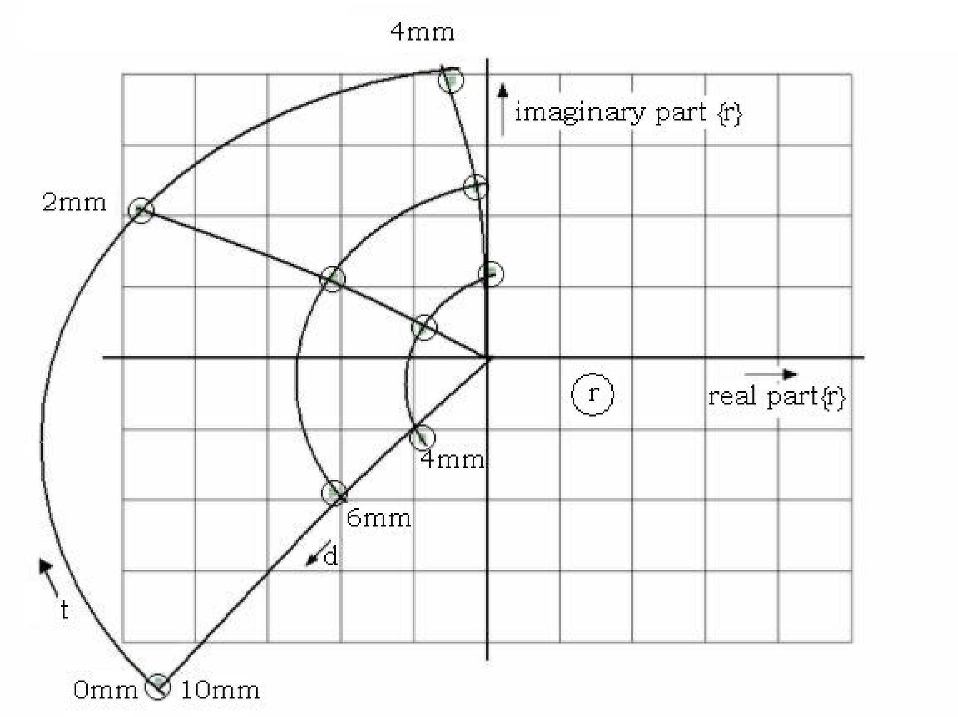
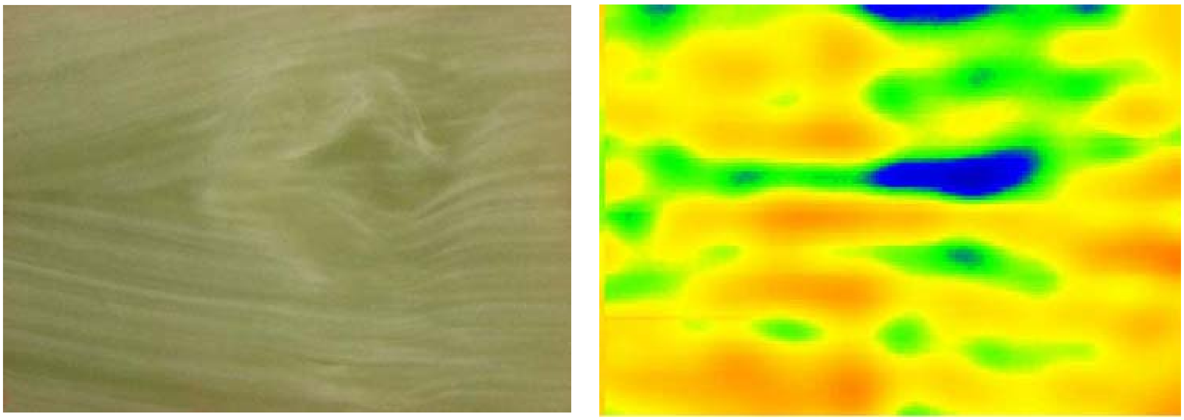


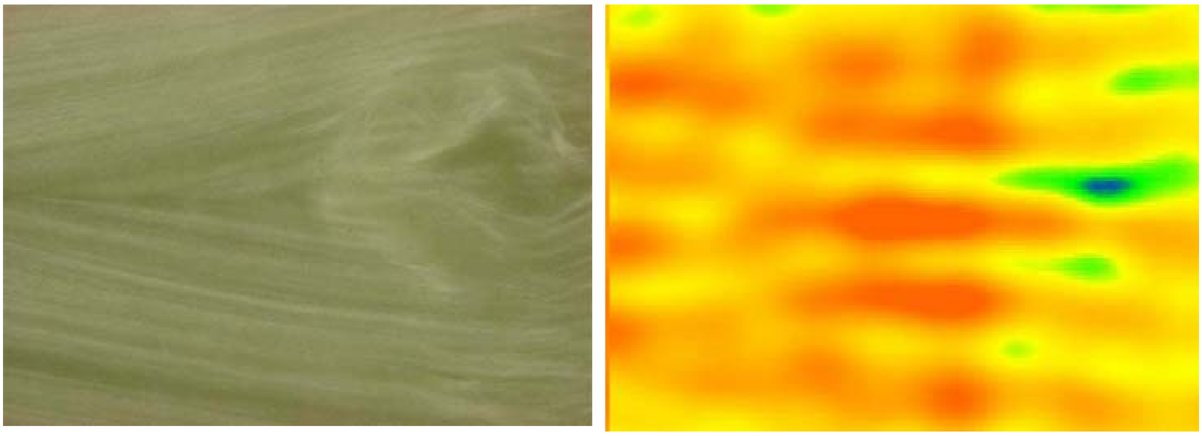
Figure 4: Maximum deflection and angle of the signatures of figure 3, displayed in the complex plane of the reflection coefficient r. d - diameter of FBH, t - residual wall thickness

By using a standard eddy current system, also its additional functions are useful for the microwave testing: amplification adjustment, filtering, threshold function, C-scans of absolute value, phase, real part or imaginary part, statistical evaluations etc.
Figures 5 and 6 show C-scans as an example.



a) b)

Figure 5: Part of flat spring made from laminated glass fibre reinforced plastic, liftoff 2.0 mm.
a) photograph of the scanned area, b) C-scan of imaginary part (y-deflection) of microwave signal



a) b)

Figure 6: Part of flat spring made from laminated glass fibre reinforced plastic, liftoff 0.5 mm.
a) photograph of the scanned area, b) C-scan of imaginary part (y-deflection) of microwave signal

The device under test (DUT) is a flat spring which is made from laminated glass fibre reinforced plastic. It contains a fibre ondulation in the outermost layer, which can be seen visually, see figures 5a and 6a. It is unknown if the ondulations are also present in deeper layers. In figure 6 the liftoff is smaller and therefor the microwave penetration into the DUT is deeper than in figure 5. The indication of the ondulation in figure 6 is less pronounced than in figure 5. From this it can be preliminary concluded, that in deeper layers the ondulations are less pronounced than in the outermost layer or even absent.

3. Conclusions

It has been shown how a standard eddy current test system can be extended such that it is useful for microwave based defectoscopy, performed on parts from plastic or fibre-reinforced plastic. Especially, it was shown that the defect signatures in the complex plane are similar to those known from eddy current testing of metal devices. Therefore, the interpretation of the microwave test results will be easy for an experienced eddy current inspector.

The principle was shown using a polypropylene plate with flat bottom holes having various diameters and residual wall thicknesses. Other systematic features of the signatures are to be expected for other dependencies, for example caused by changes of liftoff and metallic inclusions. For a quantitative evaluation, as common in NDT, a calibration of the test method will be necessary.

This work was to present a new test and evaluation principle, which is filed for a patent [6]. For the detectability limits of microwave based testing we refer for example to [2].

4. Acknowledgement

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5. References

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