ZACHODNIOPOMORSKI UNIWERSYTET TECHNOLOGICZNY W SZCZECINIE

PRZEMYSŁAW ŁOPATO

Detekcja i identyfikacja defektów struktur dielektrycznych i kompozytowych z wykorzystaniem fal elektromagnetycznych w zakresie terahercowym

Szczecin 2018

Spis treści

Summary

Detection and identification of defects in dielectric and composite structures using terahertz electromagnetic waves

Non-destructive testing is (in terms of technical structures safety) an extremely important issue related to various industrial branches including, but not limited to the construction, aviation, shipbuilding and machinery industries. This kind of testing allows to determine the properties of structures and to detect the conditions, which create a threat of damage or destruction of examined objects. The study presents the terahertz non-destructive testing technique with pulsed excitation (time domain spectroscopy, TDS) as well as the development of the new, practical methods of the detection and identification of defects in dielectric and composite structures. New solutions and modifications of the existing ones are proposed. These solutions allow detecting defects in dielectric structures in a more reliable way. The automatic identification methods for various types of the materials heterogeneities have also been developed.

At the beginning of the study the composite materials, the defects, which are formed inside composite materials and the various methods of these defects detection are briefly described. Then, the basic issues related to the terahertz method are discussed (the principle of operation, properties, application and types of signals obtained during measurements). Moreover, the measurement system, located at Department of Theoretical Electrical Engineering and Computer Science of West Pomeranian University of Technology, Szczecin is also described. The numerical model of the measurement system, implemented by the author in the programming environment with the use of the finite-difference time-domain method (FDTD) is also presented and formulated.

The developed algorithms for the detection of defects formed in the dielectric and composite materials which use the time-frequency distributions (TFD), the synthetic aperture focusing technique (SAFT) and the time reversal mirror technique (TRM) are presented. The use of terahertz signal analysis in the joint time-frequency domain allows to improve the quality of the results of dielectric materials inspection (including polymer composites widely used in various industries) and the waveguide structures. Furthermore, the SAFT method, modified by the introduction of the time-frequency transformation is proposed. This method provides the higher values of the signal-to-noise ratios, which is particularly important for the detection of defects and their distinguishability in the process of automatic identification. The TRM method consists in the excitation of the wavefront, which interacts with the material under study, on its registration by the transmitting-receiving matrix and on the retransmission of the signal reversed in time. The secondary wavefront focuses on the original source and on any scattering objects such as defects. The study presents the implementation of the TRM method for the terahertz inspection with the pulsed excitation and the criterion for determining the time of the wavefront focusing which has a clear extreme allowing to

increase the precision of determining the focusing time and thus the position of the defect under detection.

The study also presents the results of the research on the identification of defects detected in the composite materials. This follows the global trend in the non-destructive testing related to the creation of systems for automated defect recognition (ADR). It is proposed the optimum set of the obtained signals features, which allow to identify the structure heterogeneity (basalt fiber reinforced polymer composite) by means of the supervised artificial neural networks and self-organizing maps (SOM). The supervised neural identification based on the features determined in the combined time-frequency domain allows obtaining better results than in the case of the features calculated in the time and frequency domains separately. If the information about the types of heterogeneities in a given material is not available, it is possible to detect and cluster them due to the similarity of the signals features by means of the neural self-organizing structures. Such analysis may be very useful when the examined material is new, if no test measurements have been made or if a measurement database for different types of defects is not available. The conducted experiment confirmed the possibility of detecting and clustering particular types of defects in the case of real inspections of composite materials containing both defects formed in the production phase and in the operation phase.

The selected practical problems related to the terahertz inspection of various composite materials are also discussed in the monograph. The examination of the adhesive joints, monitoring of the adhesive hardening process and the penetration of moisture into dielectric materials (in particular in wood) are described.

The possibilities of the use of pulsed excitation terahertz tomography for dielectric materials testing are presented the final part of the book. The computed terahertz tomography (THz CT) system made by the author is described. As a result of the performed work, a different content of the information about the internal structure of the tested dielectric object resulting from the use of the reconstruction based on various parameters of the received signal have been observed. This information can be complementary, therefore a reconstruction algorithm which uses the inverse Radon transform and data fusion (by means of the artificial neural network) obtained from the selected set of parameters is proposed. The verification of the algorithm using the results of the various shapes dielectric phantoms inspection was made. Based on proposed assessment criterion, a clear reconstruction quality improvement has been noted, resulting from increasing the number of utilized parameters. The applied algorithm enables correct reconstruction of the internal structure of the examined object (together with the existing defects), with the reduced blurring of the obtained cross-sectional images.