Załącznik 3

Autoreferat providing a description of the applicant scientific achievements

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1. Synthetic description of the applicant's profile

1.1. Diplomas and academic degrees

PhD Eng. – Doctoral studies (2001-2005) at the Faculty of Mechanical Engineering and Aeronautics of the Rzeszow University of Technology completed with the doctoral thesis *Structure state assessment and damage detection in their elements* in discipline *mechanics* (structural dynamics), 2009.

MSc. Eng. – Rzeszów University of Technology, Faculty of Civil and Environmental Engineering, *civil engineer* course, *civil and engineering constructions* speciality, *computer aided design and construction theory* specialization, 2001.

1.2. Information about employment in scientific units

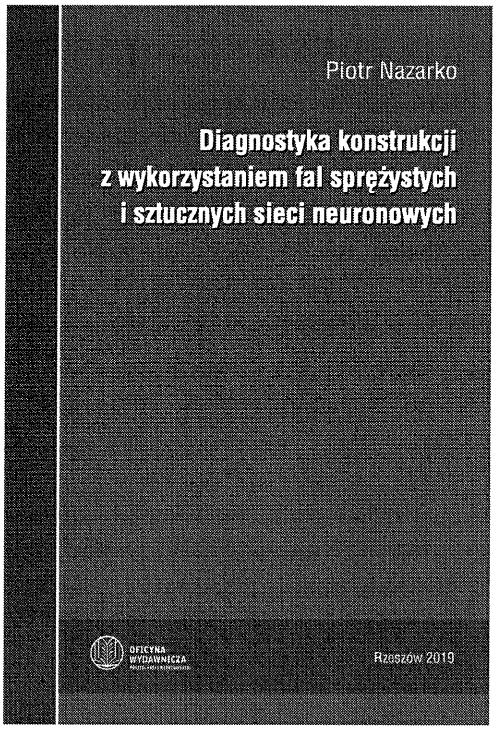
since 2009	–	**assistant professor**, Department of Structural Mechanics, Faculty of Civil and Environmental Engineering and Architecture, Rzeszow University of Technology.
2007–2009	–	**scientific assistant**, Department of Structural Mechanics, Faculty of Civil and Environmental Engineering and Architecture, Rzeszow University of Technology.
2005–2006	–	**scientific assistant**, Institute of Steel Structures, Aristotle University of Thessaloniki, Greece.
2001–2005	–	**instructor**, Department of Structural Mechanics, Faculty of Civil and Environmental Engineering, Rzeszow University of Technology.

1.3. Main scientific interests

The main areas of my scientific interests are: non-destructive damage detection and assessment techniques (NDT), the application of soft computational methods (neural networks, genetic algorithms) in classification and identification tasks, structural health monitoring (SHM), the application of the elastic waves propagation phenomenon, mechanics and structural dynamics, finite element method (FEM), measurement data processing, non-contact measurements using laser Doopler vibrometers (LDV), 3D laser scanning.

1.4. Indication of scientific achievement

My scientific achievement is a work published as a habilitation monograph entitled *Structural diagnostics using elastic waves and artificial neural networks*, Publishing House of the Rzeszow University of Technology, Rzeszow, Poland, 2019.



The monograph discusses selected examples where the phenomenon of elastic wave propagation and artificial neural networks (NNs) were used in the field of structure diagnostics. The proposed algorithm allows to undertake two-stage identification, consisting of the classification of patterns related to anomalies detected and the prediction of their parameters. Its operation was verified through laboratory tests performed on different specimens (band, sheet, rod systems, screw) made of various materials (steel, aluminum, GFRP and CFRP composite). The obtained results allowed to compare different inference algorithms (ANN, SVM, SNN) as well as the influence of applied measuring techniques (contact and non-contact) on the sensitivity and the accuracy of diagnostics.

Apart from examples of the research focused mainly on the detection and identification of failures, the monograph contains two examples where NNs and elastic waves signals were used in order to predict axial forces and to identify material parameters.

The discussed results of the pattern classification and the prediction of identified parameters, supported by numerous examples of experimental research, make a significant contribution to the popularization of soft computational methods and their practical applications in the area of non-destructive tests (NDT) and structural health monitoring (SHM) systems. The great advantage of the presented idea is the ability to automate processes related to signals registration, processing and inference, which accelerates the diagnostics, increases the availability of inspections and allows the implementation in on-line monitoring systems.

The most important elements of the monograph and conclusions are discussed in chapter 2.

2. Characteristics of scientific achievement

2.1. Introduction

The interdisciplinary nature of the structural diagnostic methods and tools (NDT/SHM) causes that this topic is willingly studied by researchers from various fields of science. These include issues related to numerical simulations, structural mechanics, experimental tests, mechatronics, automation, metrology, measurement data transmission, its processing and analysis, electronics and information technology. Issues discussed in the monograph aim to systematize the knowledge in a particular field of research methodology (the phenomenon of elastic waves) and inference tools (neural networks). It also shows the considerable potential of diagnostic systems through the practical examples of their possible applications.

The first chapter of the monograph contains an introduction to the subject of non-destructive tests based on the phenomenon of elastic waves propagation and the application of artificial neural networks.

The second chapter presents the idea of a diagnostic system that can be used to structural health monitoring of various structures and its components. In the post-doctoral research activity the author has analysed the possibility of using the developed system with respect to signals measured in samples made of composite materials (GFRP/CFRP) and in the laboratory model of a steel frame. He also presented the concept of using the discussed idea in the surface elements test which was verified on the basis of the experimental data.

The second chapter contains also a description of the elastic waves propagation phenomenon as well as the applied measuring techniques and methods of signals processing. Among the inference methods and algorithms standard neural networks (SNN), auto-associative networks (ANN) and support vector machines (SVM) were considered. The idea of binary decision trees (DT) was discussed in the chapter as well.

The examples of using the elastic waves propagation phenomenon in combination with the inference methods based on soft computing and collected in the monograph can be divided into four groups of issues:

- anomaly detection and classification of its types (e.g. discontinuities, damage, defects),
- parameters prediction of the detected changes (e.g. their size or position),
- identification of internal forces,

- identification of material parameters.

The first two issues are related to the results of laboratory tests carried out on samples made of various materials (aluminum, steel, GFRP and CFRP composites) and with various types of discontinuities (cuts and holes simulating damage, impact damage, high temperature and chemical agents). This group includes also results of the tests carried out on the steel frame model. They consisted in detecting changes caused by the loosening of the selected row of bolts in the beam-column connection (Chapter 3).

The continuation of these issues is a discussion of the research results related to the influence of:

- different techniques and measurement tools on the inference accuracy (Chapter 4),
- deterioration of signal quality by its decimation, change of time base, noising and windowing (Chapter 5).

The third of the issues discussed is a result of an attempt to identification of forces in a compressed bar and in bolts of a flange connections subjected to static tensile tests (Chapter 6). This issue is very important due to ensuring safety and integrity of structures. Identification of forces during the use of building structures allows also a better understanding of their behaviour and planning of possible inspections or renovations.

In the task of the compression force identification, a didactic stand for investigation of bars buckling behaviour was used. A few series of measurements were carried out within the load range from 50 to 2000 N. The recorded elastic wave propagation signals were used to create a patterns database and to predict the magnitude of the axial force.

The second task of the axial force identification based on the results of tests performed on flange connections subjected to a static tensile test in a strength machine. Four out of the six screws were equipped with force sensors in the form of washers. At the same time, piezoelectric transducers (served as actuator and receivers) were mounted to the selected screws to record elastic wave signals. It was observed during this study that changes in the load level cause also changes in the recorded signals. On the basis of this observation, an attempt was made to apply elastic waves and neural networks in the task of identification and monitoring of forces in bolts. This issue becomes important especially in the case of compressed connections, because due to the phenomenon of steel relaxation, the compressive force may decrease over time.

The last of the discussed issues concerned the identification of material parameters (Chapter 7). It was assumed that it is possible to locally determine the Young's modulus of the examined part of the surface element on the basis of changes in the experimentally determined dispersion curves. The elastic waves dispersion and multiform phenomenon take place in materials, which thickness is comparable with the wavelength (Lamb waves). The set of the needed data to train neural networks was generated using a semi-analytical numerical solution. On the basis of this, the sensitivity analysis of the selected material parameter to the dispersion curves changes was performed. Experimental measurements were carried out on panels made of steel (isotropic material) and composite (orthotropic material). Despite the observed lack of full compliance between numerical and experimental data, the presented idea can be used to identify selected material parameters[1].

2.2. Examples of neural networks applications

The monograph discusses selected examples of the artificial neural networks application in the tasks of diagnostics of structures and its elements. As information sources about changes occurring in the tested samples and models, time signals of elastic wave were used. The presented algorithm allows the implementation of a two-stage identification task consisting in the classification of patterns and the parameters prediction of detected anomalies. Its operation was verified with respect to elements of various shapes (strip, panel, round bar, beam-column connection, screw) and made of materials currently used in construction (steel, aluminum, GFRP and CFRP composites). The results allow to compare different inference algorithms and measurement techniques due to the sensitivity and accuracy of diagnostics.

At the first stage of the identification, the discussed examples consisted of **classification changes tasks** related to:

- notches introduced into the steel strip (an example of a complex signal difficult to visual investigation),
- thermal damage in the GFRP composite strip,
- damage (chemical corrosion and impact) in the GFRP composite panel,
- loosening of selected bolts rows in the beam–column connections (steel frame),
- holes with different diameters drilled in the aluminum strips at two positions.

In the case of the **parameters identification tasks** of detected changes (the second level of the diagnostic system), the provided examples concerned:

- prediction of the notch height and width in the steel strip,
- identification levels of thermal damage in the GFRP composite strip,
- estimation of the coordinates of anomalies introduced to the CFRP panel,
- prediction of the axial force magnitude in the compressed aluminum bar,
- prediction of the axial force magnitude in a single bolt and bolts of tensioned flange connection,
- identification of material parameters of aluminum and composite panels.

Due to the **measurement techniques** used, the following issues were considered:

- analysis of signals in the pulse–echo and pulse–transition configuration,

[1]The results discussed in the monograph are part of the work carried out under the research grant *Theoretical basis for structural health monitoring by means of inverse problem solution under uncertainty* (NCN 2011/01/B/ST8/07210), in which the author participated as a co-contractor.

- measurements in the single actuator–sensor configuration and with the use of piezoelectric transducers grids,
- comparison of measuring and recording devices based on piezoelectric transducers (LCO, PAQ) as well as non-contact measurements (LDV).

In the field of soft computing methods:

- in the tasks of two- and multi-class classification
  - auto-associative neural networks (ANN),
  - support vector machines (SVM),
  - ANN and SVM in the configuration of decision tree (DT),
  - standard neural networks (SNN) with class labels assigned to the output;
- in parameter identification tasks – standard neural networks (SNN) for regression tasks.

Most of the examples presented, except one regarding the identification of material parameters, were based on the results of experimental measurements. These tasks were divided into five groups, which correspond to the subsequent chapters of the monograph. The most important results and conclusions are presented in the next subsection.

2.3. The most important results and conclusions

2.3.1. Classification and identification of changes

The experimental tests consisted in measurements of elastic waves propagating in steel and GFRP strips, GFRP/CFRP composite panels and in elements of the laboratory steel frame model. The use of PCA allowed to reduce significantly the dimensionality of signals database and to use principal components in the training process of the diagnostic algorithm.

Obtained results of anomaly detection showed that in the case ofanalysed and investigated material samples of the construction models, it was possible to detect the implemented changes, even at an early stage of their development. The classification allowing for the separation of patterns related to various types of anomalies and normal state has been successfully performed using ANN and SVM. It was also possible to separate intermediate classes associated with successive stages of damage growth or other types of discontinuities when the ANN or SVM organized in the DT structure were used. In addition, in the case of the GFRP panel, SNN has been used to identify individual damage cases for regression tasks. It has enabled for error-free separation of all considered damage scenarios.

At the second level of diagnostic algorithm the SNN was used for the purpose of damage size identification. In case of the notch introduced into the steel strip the accuracy obtained of its height and width estimation was from $5 \cdot 10^{-6}$ to 0,567 mm. In the case of the CFRP panel, it was possible to detect all simulated anomalies associated with the variable position of the screw clamp. Unfortunately, due to the lack of repeatability observed in few registered signals, the accuracy of the anomaly location was affected by a significant error ($R^2 = 0{,}781$).

In case of the steel frame laboratory model, the classification carried out by using ANN allowed to state clearly that failure has appeared and indicate to which node it applies (left, right). Thanks to this, it was possible to point out the frame node that requires technical control of the bolts tightening torque. These tests should be continued, because at the current stage the obtained results of the classification did not allow to indicate more precisely which bolt row was loosened. However, it can be assumed by analogy to the example of patterns separation in the GFRP panel, that this task can be solved using SNN for regression tasks.

2.3.2. Comparison of measurement techniques

Experimental tests utilizing three different measurement techniques were carried out on two aluminum strip. a digital oscilloscope (LCO), phased array acquisition system (PAQ) and a 3D laser Doppler vibrometer (LDV) were used to record elastic wave signals. The test samples were drilled with different diameters to simulate the appearance of damage.

On the basis of the performed simulations of the diagnostic system training it was found that in the analysed case the highest classification accuracy was achieved by using data recorded by a digital oscilloscope (LCO). In contrast, the biggest error of classification was related with the results of NN trained using signals registered with the laser vibrometer (LDV), especially in the case of X and Y velocity components – in the plane of the sample. In this case raw measurement data were used (without filtering) to calculate principal components of the signals.

However, the obtained results should not be considered too categorically, because the sampling frequencies of the elastic wave time signals differ significantly (depending on the measurement system used). It is also worth noting that the implementation of non-contact measurements does not guarantee that the laser beam hits exactly the same measuring point each time. The examined strips were disassembled many times and despite placing a check mark on them, the accuracy of the laser beam location at the adopted measuring point is difficult to verify in practice. For this reason, one of the possible directions of further work should be related to the need of improving the accuracy of non-contact measurements and the uncertainty of measurement should be taken into account while training the diagnostic system (e.g. considering measurements at several positions of the laser beam around the control point or by random shifts of measured signals over time – its range can be determined experimentally).

In the future work, it is worth expanding this task and checking the operation of the diagnostic algorithm at the second stage of identification. In this way estimating of the drilled hole diameter can be achieved. This will allow also to verify the accuracy of inference based on various measurement systems.

2.3.3. Signals of reduced quality

The conducted research consisted in artificially lowering of the quality of measured signals by its decimating, windowing and noising. Their goal was to reduce the amount of the processed data, which affects the computation time and effort. The obtained results showed that it is possible to signal the occurrence of failures based on signals with a relatively low sampling rate. Moreover, it seems that seemingly illegible parts of the signal (due to multiple reflections from the edge of the sample) can carry a significant amount of information about the state of tested elements and the damage occurrence. From the point of view of training the diagnostic system based on pulse–echo signals, it can be expected that the most information about the tested element state will be located in further parts of the elastic wave time signal, not at its beginning. This was most evident when the pattern database was extended with signals affected by artificially generated random noise.

Considering the classification results in the case of a time window moving along the time axis, the diagnostic system was able to detect the damage even in the case of quite complex signals that are completely unsuitable for visual assessment (example of the GFRP strip). In addition, the decimation and selection of narrow time windows are able to speed up the computation at the stage of signal processing. Performing a similar analysis in the classification or identification task of specific damage types enables setting such measurement parameters that will enable anomaly detection and identification of its details at an acceptable level of accuracy.

Although conducting of similar tests is time-consuming, this problem may require further investigation with respect to other types of damage.

2.3.4. Identification of axial forces

The axial forces identification task is related to the results of two experiments involving the analysis of elastic wave signals propagating in a compressed aluminum bar and tensile bolts of a flange connection.

The obtained test results prove that on the basis of elastic wave parameters changes, it was possible to estimate the magnitude of forces in the analysed rod subjected to compression. In the load range up to 2000 N, the largest errors of predicted axial force did not exceed 80 N, which is 4% of the load range.

Neural networks were also able to find a relationship between changes of the forces magnitude in the bolts and the determined parameters of the registered elastic waves signals. The relative error of the performed estimation was less than 2% when the testing and validating patterns were uniformly selected. It turned out, however, that the designated principal components of the measured signals do not contain sufficiently accurate information to accurately perform estimation of the axial forces in the bolts that were not included in the training database, even with respect to the same connection. Signals measured in individual bolts showed quite significant differences between each other and probably that is the reason why at this stage of the study trained SNN did not have adequate generalization capabilities to predict the magnitude of unknown forces with satisfactory accuracy. Therefore, this issue requires further investigation in future work.

2.3.5. Identification of material parameters

The task of identifying material parameters of the aluminum and composite panels was based on changes in the determined dispersion curves. The patterns database was created on the basis of a semi-analytic solution and then it was used to train SNN.

An estimation of the identified material parameters (mainly the Young modulus) was expected on its output. The possibility of describing the determined dispersion curves by parameters of the approximation function and narrowing their range to a specific frequency band were analysed.

The results obtained for the isotropic material are in good agreement with the values that were estimated using other methods. In the case of orthotropic material, the approach of matching the experimentally determined dispersion curve to the data from the patterns database was analysed in order to estimate the material parameters. The least squares method (LS) was used for this purpose. Differences in the identification accuracy depended on the selection of the dispersion curve (A_0 or S_0 form). This raises a certain doubt of how accurately the semi-analytic model used describes the analysed phenomenon of the Lamb wave dispersion. However, having the appropriate (coherent) database of dispersion curves, it can be assumed that both of the presented approaches will bring the expected results.

The author's achievement was to propose a concept in which the SNN input vector is defined directly using four values of the wave numbers instead of describing dispersion curves by coefficients of the approximation function.

2.4. Conclusions from the conducted research

The main objective of the monograph was to demonstrate the possibility of using the proposed diagnostic system to detect various types of changes in the tested samples and models made of various materials, as well as to identify their parameters. On the basis of the research results it can be concluded that:

- it was possible to build a two-stage diagnostic algorithm realizing two stages of identification of changes (caused by various factors) appearing in constructions and its elements,
- soft computational methods (ANN, SNN, SVM) and elastic waves can be successfully used in the tasks of detecting and assessing changes of various origins (defects, damage, corrosion, load changes),
- the proposed approach is not limited to the specific type of anomalies neither the type of material from which the tested object is made (different variants were analysed),
- presented diagnostic algorithm allows for inference based on simple as well as complex signals of elastic waves registered in various configurations (e.g. impulse–echo, impulse–transition),
- application of ANN and SVM in the DT system allowed to perform error-free multi-class classification of the analysed changes, which has improved the results obtained earlier,
- good results of multi-class classification were also obtained thanks to the use of SNN for regression tasks,
- it was possible to detect defects at an early stage of their development (in relation to the smallest of considered notches, hole diameters, thermal damage etc.),

- in specific applications, it was possible to reduce the quality of signals; moreover, the correct classification of patterns has been obtained (also in the case of damage at an early stage of development),

- the classification accuracy and convergence of the training process proved to be better when signals were registered by piezoelectric sensors (LCO, PAQ) than non-contact techniques (LDV),

- analysis of principal components (PCA) usually allows to extract parameters from the signals of elastic waves that correctly describe their characteristics (changes), significantly reducing the size of NN input vector,

- the presented approach allows the automatic processing of measurement data and the inference process, which is of great importance in structural health monitoring systems (SHM).

2.5. Original work elements

The diagnostic system idea presented in the monograph and the carried out experiments contribute to development of non-destructive techniques and structural health monitoring. Among the significant and original elements of the research, the following achievements can be distinguished:

- verification how the discussed diagnostic algorithm operate in relation to GFRP and CFRP composite materials – its operation was previously verified based on the example of strip made of isotropic materials,

- application of the developed diagnostic algorithm in the analysis of two-dimensional elements based on sensor networks,

- application the idea of decision tree (DT) for multi-class classification using ANN and SVM,

- comparison of accuracy and convergence of the diagnostic system training process based on various measurement and recording techniques – in the case of two aluminum strips investigated the data obtained using piezoelectric transducers allowed to achieve an accurate patterns classification, whereas the inference utilizing of non-content measurements was affected by greater error,

- the ability to carry out the inference based on signals with significantly reduced quality (decimation, noise) and limited to the selected range of the elastic waves signals (windowing) has been proved,

- in case of impulse–echo signals it has been shown that there are regions, usually associated with subsequent wave transitions through the damaged area, which carry much more information than in the first wave package or even in the pulse–transition configuration,

- an attempt was made to identify axial forces in compression and tension elements,

- it was shown that sensitivity of dispersion curves to changes in material parameters is not the same (e.g. they are more sensitive to changes in Young or Kirchhoff modulus and density than to variations in material thickness) and is different for the A_0 and S_0 curves analysed,
- it was shown that it was possible to limit the range of dispersion curves to the selected frequency range and the wavenumbers point may be treated as values of NN inputs vectors – it simplified the definition of patters database and allowed the material parameters estimation.

The tasks of classifying patterns and predictions of identified parameters, supported by various examples, make an important contribution to the popularization of soft computational methods and show their practical applications in the area of non-destructive test (NDT) and structural health monitoring systems (SHM).

2.6. Practical applications

The diagnostic system discussed in the monograph enables the implementation of selected levels of structural state identification. It was mainly related to anomaly detection, damage classification, size and position prediction. There were also presented examples of dealing with parameters identification tasks (e.g. Young modulus of investigated material), loads and internal forces prediction. An application of the investigated idea is also possible in other issues related, for example, to the safety of structure and estimation of the remaining life time. Each time it will require building a patterns database (numerically or experimentally), taking into account specific locations of measurement points and various scenarios of cases related to the normal and abnormal state of the construction operation.

In addition to the potential applications of the developed approach in the diagnostics of various types of engineering structures and their components, it is also possible to implement this approach to non-destructive test of machines and devices. The big advantage of the discussed idea is the ability to automate processes related to signals registration, processing and inference, which greatly accelerates diagnostics, increases the availability of inspections and is necessary in real-time monitoring systems.

2.7. Directions for further research

The examples discussed in the monograph do not fully cover all the issues related to the investigated research area. As a result of this study, even more issues appeared that were not fully explained and still require further investigation. Many of them remain open and waiting for solutions or explanation. As directions for further research activity related to the application of elastic waves propagation phenomenon and artificial neural networks in the diagnosis of structures, the following issues can be indicated:

- analysis of the inference results due to the different positions of the measurement points, which may affect the sensitivity and accuracy of the proposed approach – it can be easily done by non-contact measurements using laser Doppler vibrometer (LDV),

- prediction of fault location based on calculated NI values and application imaging methods in tasks where sensor networks were used, e.g. introducing the concept of probability density index (PDI),
- the need to improve the accuracy of non-contact measurements performed (higher resolution of sampling frequency and better precision of hitting the measuring points assumed) and taking into account their uncertainty while training the diagnostic system (e.g. considering measurements at several positions of the laser beam around the control point or by random shifts of measured signals over time – its range can be determined experimentally),
- there is a need to continue work related to the axial forces identification in bolts in order to improve NN generalization abilities and prediction accuracy, because
  - it may be necessary to use other parameters than the principal components to become independent from the signal differences in screws of a given connection,
  - the repeatability of installing piezoelectric transducers has to be improved,
  - in practice, it is more convenient to carry out measurements in the pulse–echo configuration of piezoelectric transducers and it allows to diagnose connections only with one-sided access to a bolt's head or a shank;
- conducting tests taking into account the variability of the construction operating conditions (e.g. static and non-static loads) and the influence of environmental effects (e.g. temperature changes, wind action),
- experimental test research aiming to practical applications of the presented diagnostic system in tasks of diagnosing and monitoring the condition of building structures (e.g. detection of emergency states, changes related to various types of damage, degradation of material, lowering the value of a prestressing force in bolts, supporting decision to relieve the structure or to snow removal from the roof based on the magnitude of identified loads or deflections).

The results presented in the monograph concerned the use of classical soft computing methods (SNN, ANN, SVM) in the tasks of classification and parameter identification. Recently, renaissance of these methods can be observed due to numerous applications of convolutional neural networks (CNN) in the area of image recognition. Due to this fact, as a direction of further research, the usefulness of deep neural networks in the field of NDT/SHM and the search for new methods to improve the efficiency, sensitivity and generalization ability of diagnostic systems can be also indicated.

3. Other scientific and research issues

3.1. Damage detection in the supports of curtain walls

One of the research task analysed in the past by the author concerned the damage detection in the supports of curtain walls. This issue is partly related to the topic of the habilitation monograph, but it has not been included, because the inference about the occurrence of damage was based on the displacements values, and not on the propagation of elastic waves. In this case, the point was to indicate support in which a connector can be missing. It was assumed that the visual inspection is not fully possible due to the lack of access to connections after installing the glass-aluminum façade. In order to train neural networks, numerically determined displacements were used. The control points were located on the columns and mullions of the curtain wall. A support failure was modelled by the percentage reduction of their stiffness. Due to the number of possible defects combinations and computation time of FEM model, a patterns database was limited to the selected cases only. The number of patterns generated in this task turned out to be too small to obtain a satisfactory level of the identification accuracy. Reduction of support stiffness from 50% to 80% resulted in a reduction of the absolute identification error from 27,7% to 8,6%. For this reason, the need to create a larger database of damage patterns was indicated as a further works. This should enable verification of the effectiveness of the proposed approach to fault detection based on measurements of structural displacements.

The problem of damage detection in the supports of curtain walls was carried out during the annual academic internship carried out at the Aristotle University of Thessaloniki. The author was responsible for the stage related to defining the patterns database, developing the algorithm of neural networks and the training process as well as analysing and reporting the obtained results.

3.2. Research and analysis of tool vibrations in ultrasonic aided machining processes

As a result of the research, two measurement procedures were developed using laser vibrometry to determine the oscillation amplitudes of ultrasound-assisted machine tools. Experiments have shown that despite the limitations of using the laser vibrometers for measurements outside the machining process, the developed procedures are a valuable source of knowledge supporting the optimal selection of the grinding process parameters. It has also been shown that measurements of frequency and the computed amplitude characteristics can be helpful in detecting malfunction of holder with vibration exciters.

Using a laser vibrometer, it was also possible to measure axial and radial vibrations of tools and to record the magnitude of displacements along its height (profile). The 3D measurement and the visualization possibility of the obtained results contributes to better understanding of the phenomena taking place in the operating tools.

The main objective of the research was to record vibrations and to determine the oscillations amplitudes of selected tools used in ultrasound-aided machining processes. The values measured by the laser Doppler vibrometer were additionally compared with the measurement carried out with the eddy current technique. The obtained results show compliance of the range of determined amplitudes and prove, at the same time, the validity of the developed measurement procedures. It has been shown that application of laser Doppler vibrometers is possible in order to successfully determine the amplitudes of tool oscillations. This is a valuable source of knowledge supporting optimal selection of the treatment process parameters.

The research was carried out within the framework of cooperation with the scientists associated with the Faculty of Mechanical Engineering and Aeronautics from Rzeszow University of Technology. It resulted in the implementation of a joint project in area of the Applied Research Program (PBS2/B6/17/2013) entitled *Technology of high performance machining of geometrically complex ceramic parts with ultrasonic assistance*. The result of this research is a series of publications related to the measurement and analysis of machine tool vibrations, in which the applicant is a co-author.

3.3. Application of neural networks for the calibration of microsimulation models

Road traffic microsimulation models are used to perform complex capacity analyses, traffic conditions assessment and light control logic. The definition of this models is a time-consuming and complex process. It requires not only to carry out traffic research and mapping of the road network, but also to take into account the behaviour of drivers. The process of calibration of motion models assumes a series of simulations carried out in order to obtain a base model reflecting real traffic conditions on a given road section. One of the possibilities of model calibration is the experimental method in which the user manually changes the model parameters. In order to speed up this process, it is possible to use appropriate mathematical structures that will enable generation of the best combination of variables. A method that allows proper configuration of the model is based on artificial neural networks. They are used to solve many practical problems, in which the process of obtaining the results with respect to an input data is complicated and difficult to describe or predict. The applicant cooperated in the development of a comprehensive algorithm enabling the calibration of motion models.

The biggest challenge of the model calibration was the need to test a large number of patterns in the microsimulation program, which resulted in a relatively long calculation time. In addition, the reconstruction of such a complicated algorithm is not straightforward. Therefore, in the conducted analyses a simplified calibration method using soft computing methods was proposed.

This concept consists in replacing time-consuming simulations with neural networks, previously trained for this purpose. However, their training requires creating an initial patterns database that will be used in learning process. Then, using its generalization ability, it was possible to quickly estimate the average travel times. This allowed to find a set of input parameters that correspond to the assumed travel times. The validation of these parameters in the Vissim program showed their good compatibility.

The applicant contribution is related to the development of the concept utilizing neural networks, writing an algorithm of their training, analysis and results reporting. The results of the conducted research were published in the article (Szarata & Nazarko 2017).

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