Adam Szeliziński

Development of methodology for analyzing vibrodiagnostic research in monitoring the damage of welded joints of ship constructions thin elements.

Abstract

The subject of the dissertation is the development of methodology for analyzing vibrodiagnostic research in monitoring the damage of welded joints of ship constructions thin elements. Before the work had started, a thorough analysis of the literature regarding the subject matter was carried out. Hazards resulting from negligence regarding the technical condition of the hull both during exploitation and at the production stage were indicated. Without finding clear answers to issues arising from the subject of the thesis in, it was decided to develop new diagnostics methods of ship structures welded elements. That method could be used in developed structural health monitoring system developed on board of ships.

The dissertation was done as consisting of an introduction, four basic chapters and conclusions. The first chapter describes the construction of various welded joints, however the most attention was devoted to the methods of detecting this damages. Both widely used and less well-known methods are discussed, and also non-commercialized methods are described.

The second chapter is the definition of the thesis and purpose of the work. The aim was to develop key elements of a structural health monitoring system (SHM) thin welded structures with defects, with particular emphasis on the hull structure. Based on literature research, it was assumed that the planned SHM system will be based on vibrodiagnostic methods. Many elements of such a system are already well developed by other researchers. The focus was on the development of methods for analyzing vibration signals created under the influence of impulse excitations, which would be triggered either by environment or by special testing devices. The main purpose of these methods is early detection of weld joints damaged during operation. Development of this methods might prevent catastrophic maritime events. In particular, it was decided to find an answer to the question whether an autonomous SHM system can be created, using a vibrodiagnostic test that would warn an untrained ship's crew from potential catastrophic damage - a ship’s hull crack. Based on a review of the literature and the author's own experience, the following dissertation thesis has been formulated:

"It is possible to define new parameters and dynamic characteristics of ship constructions based on analyzes of vibrodiagnostic tests".

The next chapter, 3, concerns on the first stage of testing where the tested objects were considerable thick plates. A special test bed was built for the needs of this stage of work. Research was carried out for four welded plates characterized by joint damage typical for the shipbuilding industry. Plates with such dimensions are characterized by a strong diagnostic signal. An analysis of the suitability for further testing of various types of extortion (different duration of the impulse) was carried out. An exemplary image of amplitudes as a function of the vibration frequency obtained using a modal hammer with a silicone, teflon and metal tip was shown in Figure 1.

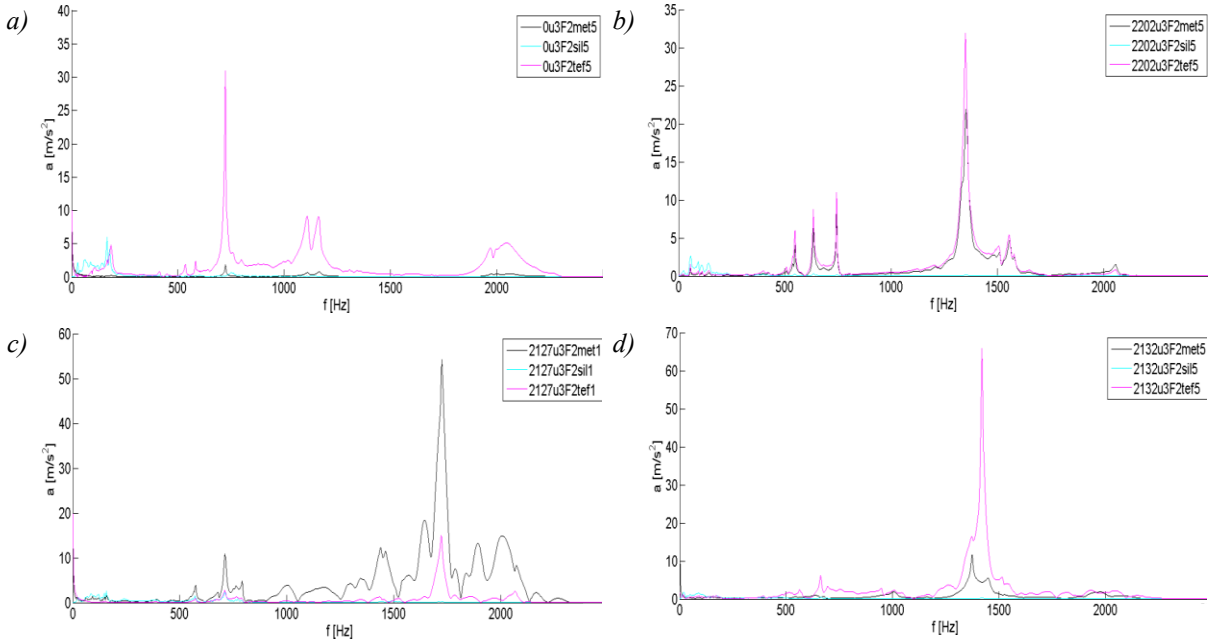

Fig. 1. Amplitude spectra of vibration accelerations for the response recorded on the plates using different hammer tips (met, sil, tef) at the impact location F2 for a) plate without weld connection - 0, b) welded plate without defects in the weld - 2202, c) welded plate with a defect such as edge sticking in the weld - 2127, d) welded plate with a defect of the crack type with a defined length in weld 2132

It was observed that the actual envelope of the impulse force signal may be far from the ideal theoretical Dirac delta. A modal hammer with a metal tip was chosen for further research. The obtained waveforms of vibration accelerations recorded at various points of the test objects were then analyzed in the frequency domain. Analysis of results obtained on first stage of research allowed to confirm the possibility of developing a system for monitoring the technical condition of ship structures based on vibration methods. Obtained signals were also analyzed according to the proposed method enabling control of vibration parameters simultaneously as a domain of time and frequency (2D and 3D analysis). An example course

of accelerations vibration amplitudes as a function of frequency and time is shown in Figure 2.

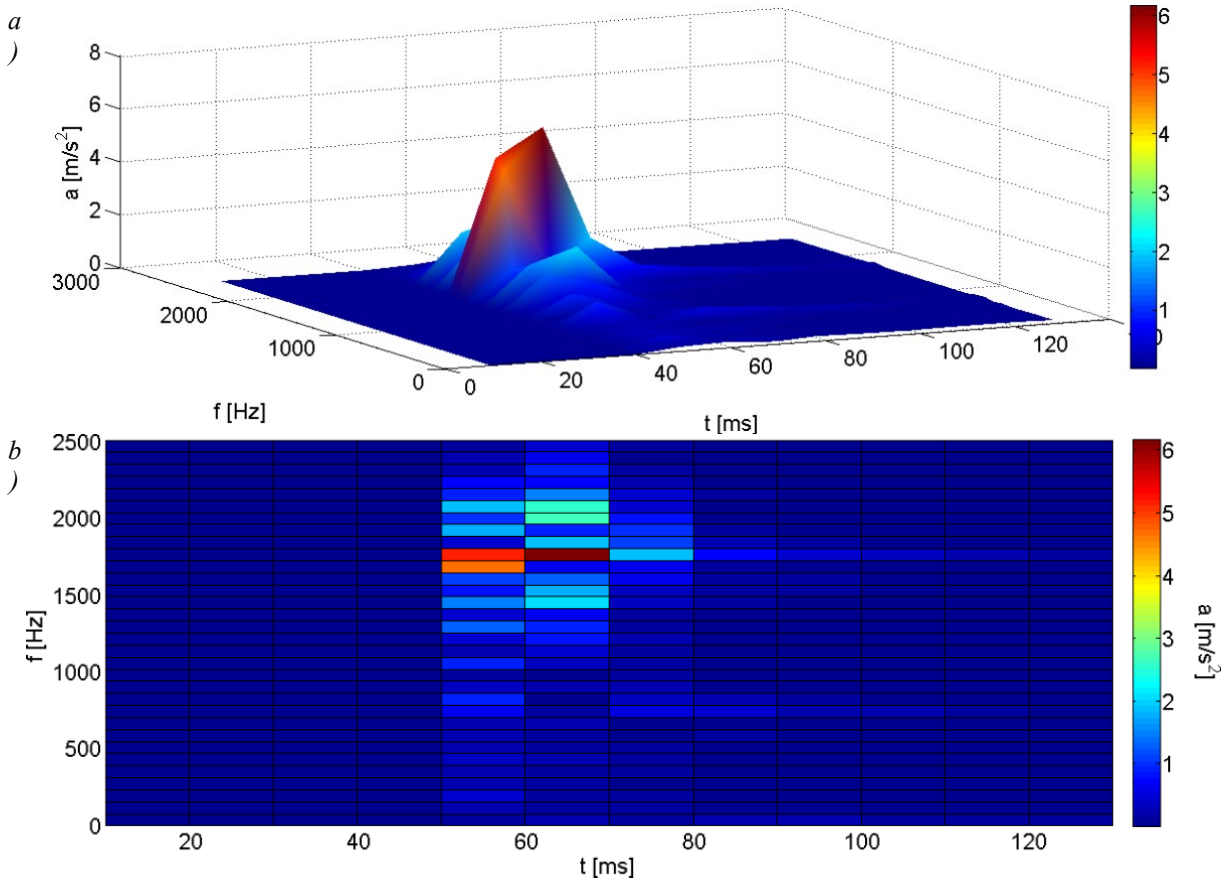

Fig. 2. a) 3D time-frequency characteristics of a welded plate with a defect like edge gluing (2127), b) time-frequency characteristics of 2D for a welded plate with a defect of edge gluing (2127) both for impacts made with a modal hammer with a metal tip

A distinct change in the time of resonant frequency distribution can be observed. Another proposed method of signal analysis is the time window method, where an average value was determined for individual windows. It was found that the values of the mean amplitude for subsequent time windows implemented for signals coming from boards with different faults take different values. The last method of analyzing the signals proposed in this chapter is the method based on determining the damping decrement. Two dependencies describing the logarithmic damping decrement have been proposed, one of them is used to determine the average damping of the structure with respect to the maximum amplitude, while the second one is used to assess the local change of damping decrement assuming knowledge of any two amplitudes of the same waveform. Changes of the damping decrement for a slab with severe weld damage are presented in the following figure 3 below.

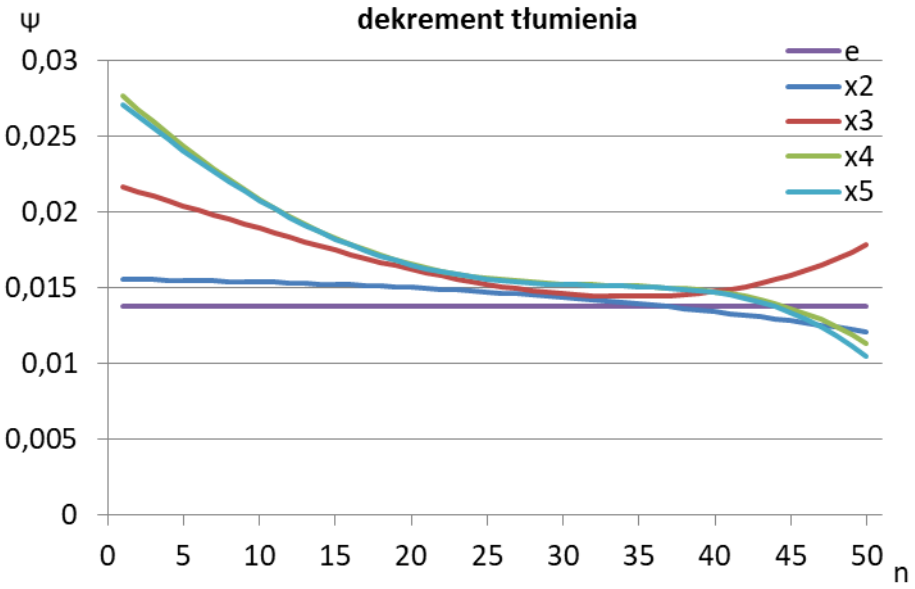

Fig. 3. Damping decrement of a welded plate with a defect of a defined length (2132) respected to the maximum value for testing with the use of a metal tip on a modal hammer

The proposed method of analysis allows the detection of non-linearity in the tested structure, and thus the detection of damage to the welded joint.

W rozdziale czwartym opisano badania blach konstrukcji cienkościennych oraz wyniki uzyskane podczas tych badań. The dimensions of thin-walled panels were chosen due to the fact that they had dynamic characteristics as close as possible to real ship constructions. The research stand for this stage of research has been equipped with a laser vibrometer that allows for non-contact measurement of displacements of the tested elements. Seven plates with the same dimensions were tested. One of them without a weld connection, the other one with a perfect welded joint and five with typical welded joint damage. The correctness of the test run was verified by comparing the amplitude spectra of vibration accelerations for ten consecutive beats with a modal hammer. Full repeatability in the frequency domain was achieved. Using the program based on the finite element method - "Patran-Nastran", the studied elements were modeled and the results of numerical modal analysis were compared to the results obtained during the measurements. An example of a FEM model with a damaged weld that has more than 1.5 million degrees of freedom is shown in Figure 4.

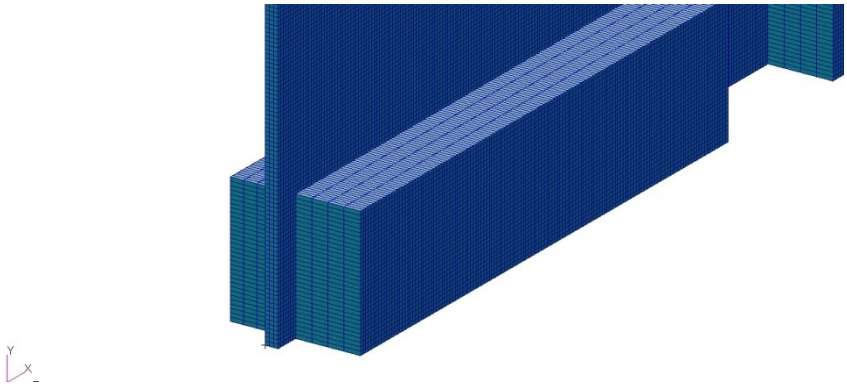

Fig. 4. The boundary conditions for individual models: 2D, 2-3D, 3-D and 3-D det

The signals obtained during the measurements were analyzed using the methods used in the previous chapter. An example of using the time window method to detect damages (non-linearity) in a welded joint is presented on Figure 5.

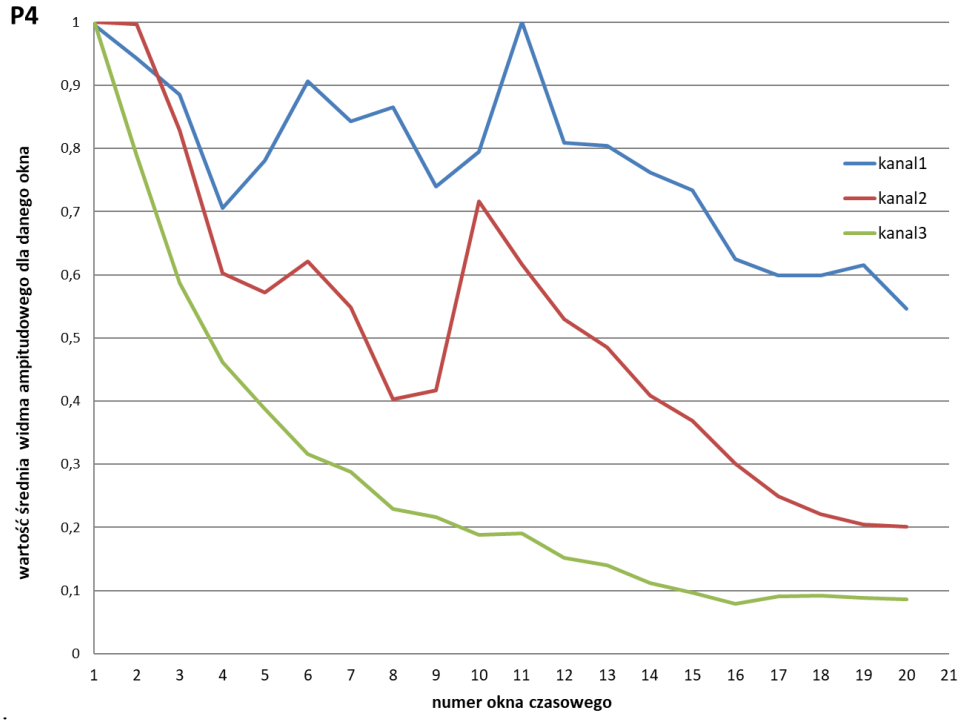

Fig. 5. Distribution of windows mean values as a window number function – plate with no weld remelting, obtained from three accelerometers

The work was finished with the conclusions. As part of work on the SHM system, it is necessary to develop a procedure that is effective from the scientific and utilitarian point of view. It might be done conducting by vibrodiagnostic tests of welded joints, by specifying: the method and place of extorting the structure and the optimal positioning of the sensors. Also important is to choose the correct measurement parameters such as time or sampling frequency. During the tests and their subsequent analyzes, it was found that in the future SHM system it may not be sufficient to use one sensor to monitor one key element. In the case of a complicated welded structure, which is the hull of a ship, the exact determination of the

number of sensors will each time require additional analysis. The sensor system should consist of at least a dozen accelerometers located mainly in the region of the canopy.

Summing up, the dissertation investigated the possibilities of detecting failures of non-linear welded joints by finding methods of nonlinearity detection of dynamic characteristics of thin-walled ship structures. The research allowed for creation of methods which might be used for quick diagnostics of thin-walled construction elements with welded joints. According to the above, the following has been developed:

- a new diagnostic measure based on time-frequency analysis of vibration acceleration amplitudes useful for initial verification of joints,
- a new diagnostic method based on time windows that can be used in SHM methods,
- a new diagnostic method analyzing changes in the damping decrement over time.

As a result of the work, the hypothesis was confirmed. The development of a package of methods for analyzing impulse signals allowing their future use in autonomous monitoring systems based on elements of artificial intelligence confirms the achievement of the main objective of the work. During the implementation of the main objective of the work, all previously set specific objectives were implemented, which were formulated as follows:

- development of appropriate methods for carrying out vibro-diagnostics tests, in particular the selection and configuration of measurement sensors, analysis of effective methods of vibration excitation, selection of diagnostic signals registration parameters, etc., from the point of view of an autonomous SHM system,
- determination of parameters and dynamic characteristics of the most sensitive from the point of view of welded defects and comparison of their effectiveness with standard techniques based on commercial NDT studies,
- preliminary development of methods for analyzing the results of vibrodiagnostic tests performed on plates with laboratory welds (selected welds will be artificially damaged); in order to pre-determine the directions of further tests, plates of considerable thickness were selected for the analysis, in which the expected nonlinear effects will be significant,
- determination of the effectiveness of the developed methods of analysis, by conducting tests of welded elements from the shipbuilding industry, with damages typical of real constructions; checking the possibility of modeling this type of damage using numerical methods to pre-verify the measurement tests,

In particular, the work resulted in the development of a specialized device for detecting damage to thin-walled structures that has been announced to be patented.