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ANALYSIS OF THE POSSIBILITY OF USING VIBRATION PARAMETERS FOR DIAGNOSTICS OF SELECTED DEFECTS IN WELDED JOINTS OF THE HULL PLATING ELEMENTS

Analiza możliwości wykorzystania parametrów drganiowych dla potrzeb diagnostyki wybranych defektów połączeń spawanych elementów poszycia kadłuba jednostek pływających

Abstract: *The article presents results of vibration tests of thin-walled plates used in shipbuilding for plating hulls of vessels. The conducted tests were aimed at determining the possibility of using measurements of vibration acceleration recorded on the tested objects as parameters enabling the detection of damages in the performed welded joints. Seven plates were compared, six of which had joints in different technical conditions, and one was a board without a weld. The quality of the welds was verified using X-ray methods. The adopted research methodology and the obtained results were presented.*
Keywords: Vibrations, defects detection, welded joints

Streszczenie: *W artykule przedstawiono wyniki badań drganiowych płyt cienkościennych wykorzystywanych w okrętownictwie jako poszycie kadłubów jednostek pływających. Przeprowadzone badania miały na celu określenie możliwości stosowania pomiarów przyspieszeń drgań rejestrowanych na badanych obiektach jako parametrów umożliwiających wykrycie uszkodzeń w wykonanych połączeniach spawanych. Porównano siedem płyt, z czego sześć miało spoiny w różnym stanie technicznym, a jedna była bez spawu. Jakość spoin zweryfikowana została metodami RTG. Przedstawiono przyjętą metodykę badawczą oraz uzyskane wyniki.*
Słowa kluczowe: drgania, wykrywanie defektów, połączenia spawane

1. Introduction

Among the various means of transport, maritime and air transport are exposed to the most significant threats. Vessels work in extremely harsh environmental conditions while being exposed to an aggressive environment that affects them for a very long time. Ships intensively used are particularly prone to critical damage, such as cracks in welded joints. This type of damage directly affects the level of navigation safety. Each maritime facility is built and operated under the classification society's supervision. They require precise safety control of a given marine structure from the moment of its design through construction to operation. Welded joints are a critical element subject to precise control under these principles [1].

NDT techniques are tests that allow obtaining information about the tested object's condition, properties and possible defects without interfering with its functional features [2]. The purpose of non-destructive testing is to determine the type, size and location of non-conformities to confirm their approval or the need to remove them from the tested element. NDT techniques are well researched and produce results with usually sufficient reliability [3]. However, they have a fundamental disadvantage - they are carried out periodically. In the periods between tests, we are not sure about the technical condition of the structure. Especially in critical events, such as a strong storm or a collision, information about the possibility of further use of the facility is essential [1,4]. This information must include the degree of risk of a potential catastrophe and the parameters of further operation. For this purpose, research into new techniques known as Structural Health Monitoring is being developed.

So far, the research with vibration methods is most often based on the resonance method [1-5, 15] and simplified modal analysis [5,6]. The changes in the natural frequency caused by damage to the structure are mainly investigated. The disadvantage of this type of research is its low sensitivity because the natural frequency depends on the elemental stiffness of the structure. Using vibration tests, the following defects can be detected: changes in dimensions, shape, mass, density and cracks. It also makes it possible to identify incorrectly performed technological processes.

Vibration damage detection systems for steel structures currently in use in the marine industry are based on a small number of sensors and are only used to detect damage to existing structures – mainly cracks [7]. The authors propose to increase the number of sensors and use vibration diagnostics of welds already at the stage of production of individual repetitive components of larger structures.

The tests were carried out with the use of welded steel plates. Certified welders performed all welds, i.e. objects found in industrial practice were tested. The tested boards with dimensions of 500x500x4 mm are, in terms of their thickness, similar to the real objects. Some of the tested plates have defective welds that were negatively verified by commercial RTG technique in one of the Pomeranian shipyards.

2. The research methodology

The vibration parameters were obtained from measurements carried out on seven plates with different joint conditions. Mostly joints with unacceptable welds were selected. All plates were tested with RTG method – figure 1. The main causes of defects in welded joints are any deviations from the correct welding technology, improper selection and preparation of basic and additional materials for welding, non-technological design solutions for joints, non-compliance with welding technology, insufficient qualifications and irresponsibility of welders, failure of welding equipment and the like.

Fig. 1. X-ray picture of the plate with edge bonding – P6

Understanding the causes of non-conformities allows for easier and more precise interpretation of the quality of joints tested with non-destructive methods, assessment of the impact of these non-conformities on the operational properties of joints and taking actions to eliminate defects in the manufacturing process of welded structures [8-13]. Due to the mechanism of their formation, welding defects are divided into technological defects (related to the manufacturing method) and operational defects caused by the working conditions of the element (e.g. fatigue cracks) [7]. The condition of joints was assessed using the radiographic method. The following types of damage were found in welds:

- P1 plate - plate without a welded joint,
- P2 plate - lack of melting,
- P3 plate - few spherical bubbles, the connection is considered good,
- P4 plate - lack of melting,
- P5 plate - lack of melting,
- P6 board - lack of melting, edge bonding, longitudinal bladder,
- P7 board - lack of melting, edge bonding, longitudinal bladder

The tested steel plates used during the tests had dimensions of 500x500x4 mm. The transmitters were assembled according to the diagram shown in Figures 2 and 3. The vibrations were caused by hitting with a modal hammer with different tips: metal, silicone and Teflon. The locations of the impacts are shown in Figure 1 by the notations F1. The tests consisted of recording the amplitudes of vibration acceleration through accelerometers designated ACC 1, ACC 2 and ACC3 (Figure 2). All measurements were repeated many times, with different impact forces, to determine the results' statistics and to detect possible non-linearities in the behavior of the measurement system.

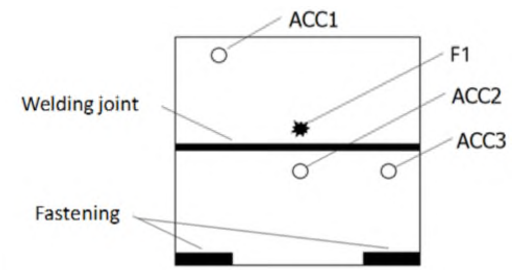

Fig. 2. Arrangement of transducers during tests. ACC1, ACC2, ACC3 - accelerometers F1 - place of impact with a modal hammer

Fig. 3. A photo of one of the tested boards with measuring sensors installed

During the measurements, time courses of vibration acceleration were recorded using the Pulse measurement system by Bruel & Kajer. Vibrodiagnostic tests were performed using the measuring equipment shown in Figure 3. The B&K 3050-A-60 measuring cassette is a measuring device that enables simultaneous measurement with the use of 1 to 6 sensors. The device used has a maximum measurement bandwidth of 51.2 kHz per channel with a sampling rate of 131.072 kHz per channel these values are independent of the number of connected channels. The cassette is equipped with a 24-bit analogue-to-digital converter. The B&K 4514 B accelerometers are piezoelectric accelerometers of the DeltaTron type made in the IEPE standard (integrated electronic piezoelectric). The use of the IEPE standard means that we obtain a voltage signal at the output of the transducer, thanks to which it is possible to use ordinary cables with one signal wire, for which there are no special impedance or low noise requirements.

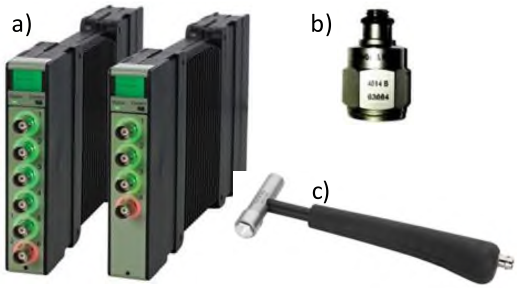

Fig. 4. Measuring system [6] with an accelerometer and a modal hammer, where: a) measuring cassette, b) accelerometer, c) modal hammer

A modal hammer type B&K 2270 was used as the element forcing the shock impulse to excite the tested plates to natural vibrations. This device is also made in the CCLD standard. The sensitivity of the modal hammer used is 2.27 mV/N and the maximum possible input that can be correctly registered with its use is 2200 N. The hammer was used in configurations with three different tips: metal (aluminium), Teflon and silicone. After the initial verification of the obtained results, only the signals excited by tip were selected for detailed analysis. In this case, the time of the forcing impulse is the shortest – fig. 5, and the response of the tested element is the most reliable.

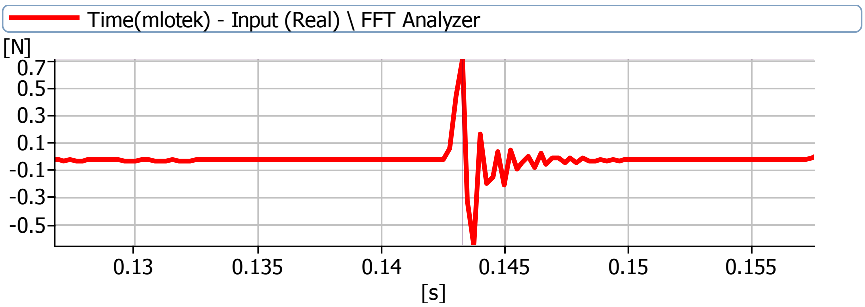

Fig. 5. Example of impact signal obtained with a modal hammer

3. The research results

In the first stage of the research, the results' reproducibility was checked. The dynamic characteristics of the tested objects, made by repeatedly carrying out a given test, with a different exciting force, were compared. Lack of repeatability could indicate improper mounting of the test object or errors in processing the measuring signal. A comparison of the P1 plate spectra for the next ten modal hammer impacts is shown in Figures 6a and 7a. In Figures 6b and 7b there is a similar comparison for the P3 plate. Figures 6c and 7c shows the spectra of 10 consecutive impacts for the P7 plate with significant defects in the plate.

It should be emphasized that the impulse forces were applied manually. Therefore, during the measurements, there was a certain dispersion in terms of both the value of the forcing impulse and its application to the tested object. The adopted methodology for the implementation of measurements is correct because it reflects the random excitations that will occur during the ship operation in the most likely way possible. The authors' assumption is to create a system that will enable the detection of damage to the hull plating that develops and develops during regular everyday operation.

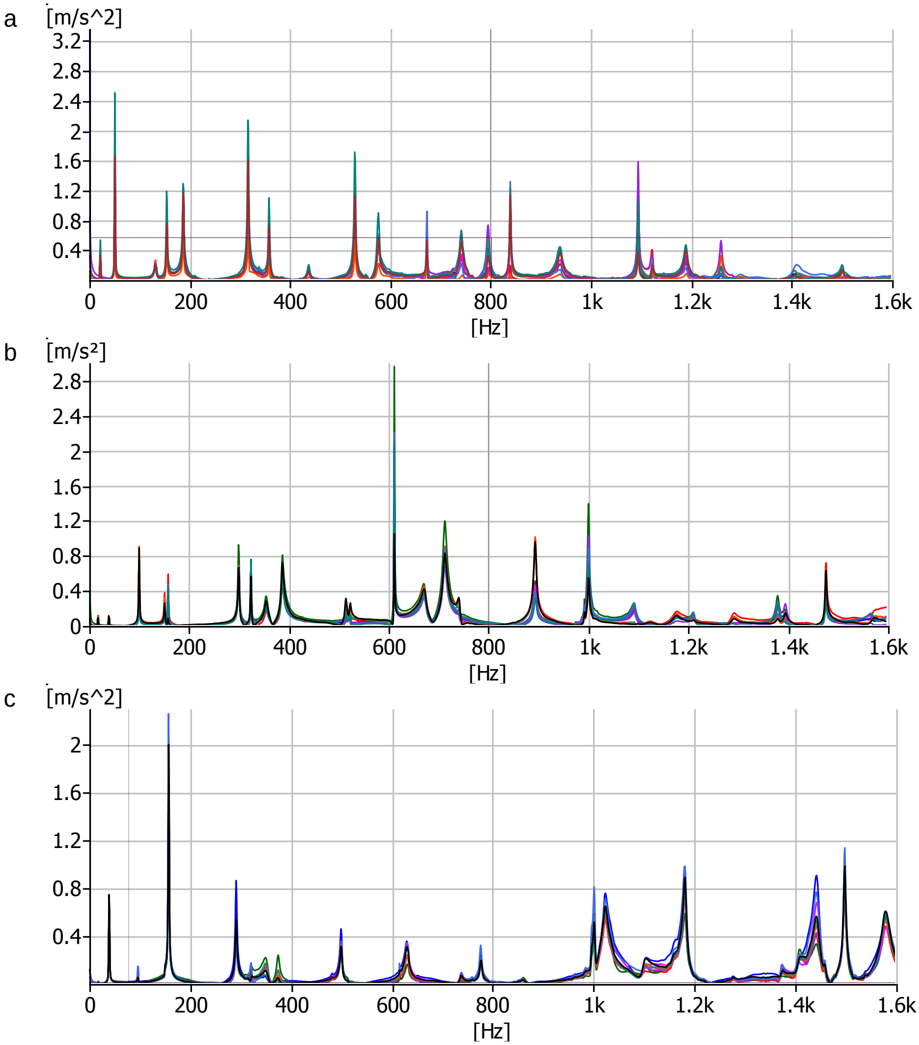

Fig. 6. Vibration acceleration spectra of the response to the modal hammer excitation for ten successive strokes of the P1 – a, P3 – b, P7 – c, plates

In Figure 7a, the frequency range of the plate P1 spectra is up to 200 Hz, thanks to which it is possible to read the values of the natural vibration modes of the plate without a weld. Results for plates P1, P3 and P7 are presented in table1.

Table 1

Plate number	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
P1	22	51	132	154	187
P2	18	39	100	151	158
P3	-	39	97	157	-

Thus, the influence of the weld occurrence and its condition on the values of the natural frequency and response amplitude is visible. This influence is also illustrated by the spectra in Figure 8.

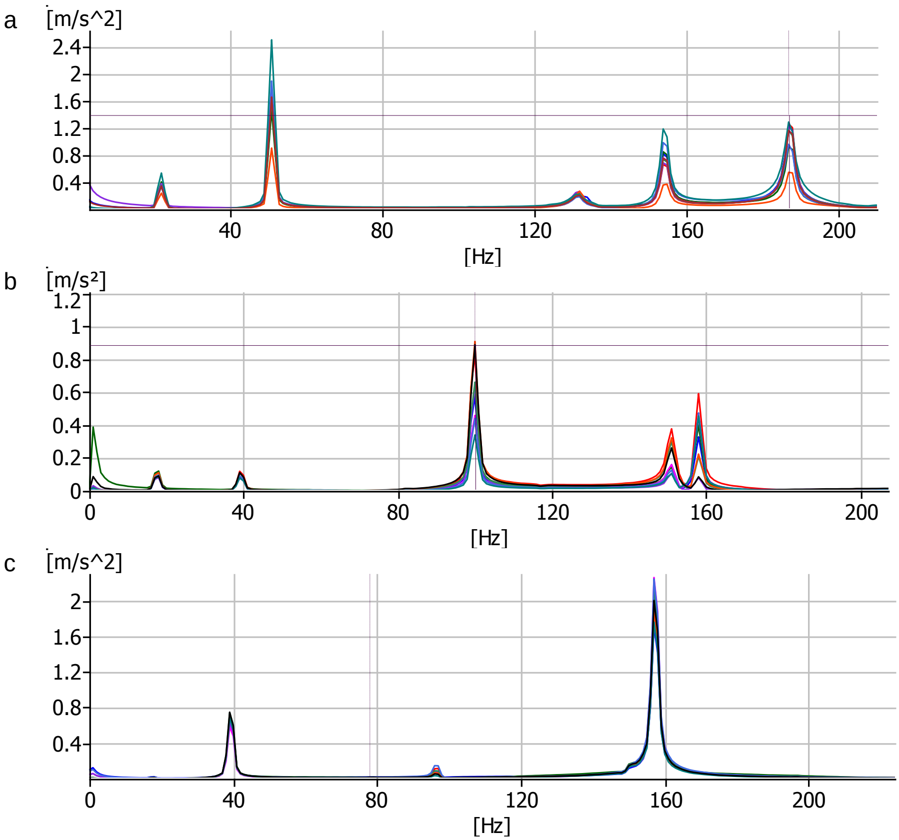

Fig. 7. A close-up of the vibration acceleration spectra of the response to the modal hammer forcing for 10 successive hits of the P1 – b, P3 – b, P7 – c, plates

Figure 10 shows a comparison of the spectra obtained during the tests of all plates. Results of all vibration modes of plate without welding joint are similar to calculated one and might be find in [3], it also confirms good methodology of researches. In figure 10, violet solid line presents spectra of P3 plate which may be considered as a welded plate with weld in good condition.

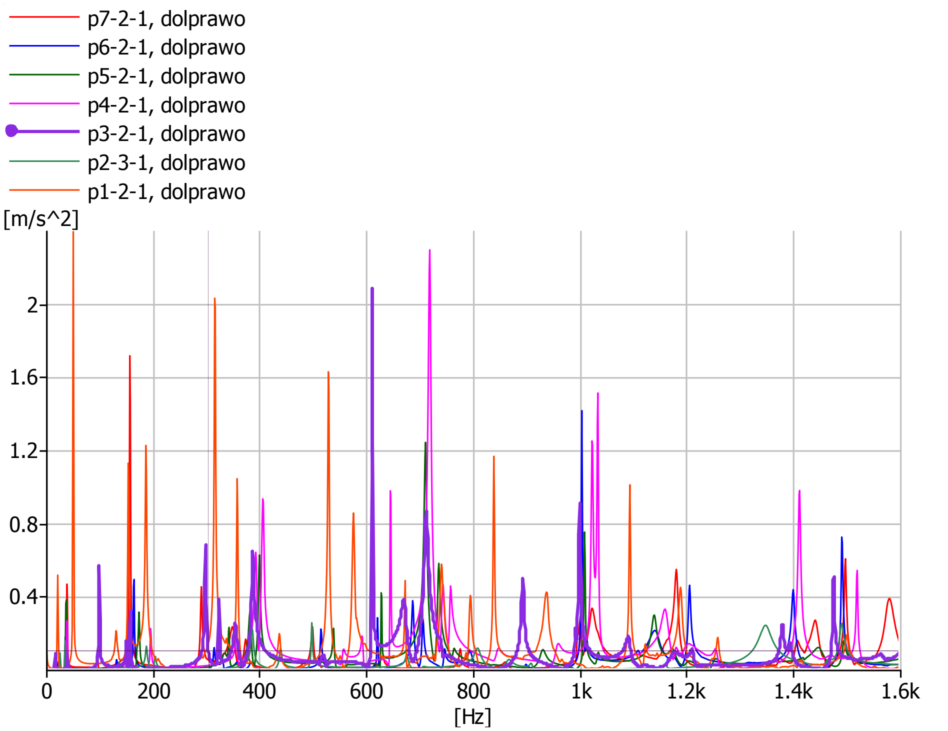

Fig. 8. Comparison of the vibration acceleration spectra of all tested plates

The presented comparison gives evidence that the tests were carried out correctly. Such a conclusion is drawn after the analysis in the frequency domain, where in Figure 5-9 all the waveforms have the same frequencies of the dominant amplitudes. In Figures 6, 8, 9 and collectively in Figure 10 one can observe the impact of the weld damage on the frequency characteristics of the tested panels - despite the identical method of panel assembly and the identical test method. This situation results from the different condition of the joints in the tested plates and, consequently, different resonance responses. Authors give an suggestion according to which tested plates should be considered as defected in a situation in which at least one of first five modes frequencies differ at least 10% from frequencies obtained on object with acceptable welds.

4. Conclusions

The tests and their results confirm the usefulness of vibration diagnostics for determining the technical condition of welded joints of thin-walled plates used as plating of vessel hulls. This method can verify the correctness of welds in repetitive elements and monitor entire ship structures. In both cases, it is necessary to collect an appropriate base of reference signals to determine the limit values of the frequency ranges of individual modes of free vibrations relating to fully operational elements. Changes in the stiffness of the elements occurring due to imperfections of the welds at the production stage or their operational damage will result in changes in the value of the natural frequency. As a consequence, it will be possible to detect any irregularities. During the conducted research and their subsequent analysis, it was found that it may not be enough in a future SHM system to use one sensor to monitor one key element. In the case of a complicated welded structure, such as a ship's hull, the exact determination of the number of sensors will require additional analysis each time. The sensor system should consist of at least a dozen or so accelerometers located mainly in the waterline. At the stage of laboratory tests, an impulse from a modal hammer was used as the input and it was sufficient, however, during tests on real objects, the author plans to use the hull stimulation resulting from its normal operation (wave operation or stimulation from working mechanism like main engine).

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