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QUALITY ASSESSMENT OF WELDED JOINTS USING THE MEAN VALUE DISTRIBUTION OF AMPLITUDE SPECTRUMS CALCULATED BY THE TIME WINDOW METHOD

Adam Szeleziński

Gdynia Maritime University, Faculty of Marine Engineering
Morska Street 83-87, 81-225 Gdynia, Poland
tel.: +48 58 5586331
e-mail: a.szelezinski@wm.am.gdynia.pl

Adam Muc

Gdynia Maritime University, Faculty of Electrical Engineering
Morska Street 83-87, 81-225 Gdynia, Poland
tel.: +48 58 6901651
e-mail: a.muc@we.am.gdynia.pl

Lech Murawski

Gdynia Maritime University, Faculty of Marine Engineering
Morska Street 83-87, 81-225 Gdynia, Poland
tel.: +48 58 5586331
e-mail: l.murawski@wm.am.gdynia.pl

Abstract

In continuous monitoring systems of welded joints of thin-walled structures, a vibrodiagnostic method is the most promising. Its most important advantage is that it is effective and offers the greatest real-time research capabilities. It is used in classic NDT techniques as well as in structural health monitoring during exploitation. This work presents a measurement method of dynamic characteristics of the structure with the use of piezoelectric sensors. The article presents the assumptions concerning the evaluation of welded joints using the analysis of the mean value distribution of the amplitude spectrums calculated by the time window method. The statistical measure used in the form of the mean value is a proposed parameter. The parameter's analysis for a given welded joint may enable an unambiguous assessment of its quality. Attention was paid to the elements important for the study. A calculation algorithm as well as and the exemplary results from the proposed method used for some selected samples with different welds is included in the article. The work contains the description of the scientific apparatus to register dynamic characteristics in case of welded joints. The results of the tests show that the analysis of the distribution of mean value for amplitude spectrums calculated by the time window method indicates that they differ markedly depending on the welds, indicating their quality and defects that are associated with them.

Keywords: *diagnostics, welded joints, non-destructive testing, NDT, SHM, vibration, spectrum analysis, time window, mean value*

1. Introduction

Non-Destructive Testing NDT is a type of testing which allows acquiring information about the state, properties and possible defects of an object without interfering in its functional characteristics. This type of testing is applied, inter alia, to welded, adhesive-bonded or soldered joints, to castings, and to the elements made of composite material [2, 4, 7]. They are used in the reliability assessment procedures and in the evaluation of the quality of the products, finished or utilized, which are under the technological processing. NDT is used to attain the adequately high quality and safety level. The opportunity to identify the type, size, and place of incompatibility in order to either accept or remove tested element is one of the reasons to use NDT. The significant feature of NDT stems from the fact that it gives a chance to define the properties and obtain a physical description of tested material [5, 6, 15].

The control activities that ensure the quality of the welded joints take place not only in order to diagnose the exploited structure but also during the production process. Their aim is to avoid unexpected damage of technical objects through elimination of the objects having some exploitation damage that jeopardizes the safety during the further usage. Non-performance of the checking activities that do not cause the damage of the technical objects (e.g. planes, ships, lifting equipment, bridges etc.) or conducting them in violation of research procedures, may lead to catastrophes or breakdowns [1, 6, 11] (Fig. 1).

Fig. 1. A maritime disaster resulted from the collapse of the hull structure

The modern systems for Structural Health Monitoring SHM can be based partly on NDT, which are used during the periodic inspections of welded structures at places where the occurrence of defects is the most likely. The fundamental difference between SHM and NDT rely on hardware architecture [10]. In case of SHM systems, the network of sensors is integrated with the object while the sensors network used in NDT is external and independent. SHM systems operate on-line contrary to NDT. The key element of SHM systems is the automation of their operations (e.g. generating the reports, informing the staff about non-standard parameters) on the base of artificial intelligence technology [10, 11].

There are many elements, which influence fast development and wide use of NDT in technology. The most crucial are safety and economics. In the development of non-destructive methods of testing, there is a general trend for obtaining the widest range of data on the degree of quality of tested element, which provides the possibility of detecting smaller and smaller incompatibilities and gathering more data about them. Such development strives to achieve the increase in execution speed and in safety as well as lowering harmful effects of used resources on operators' health. The development concerns currently used methods and the ones that have just been introduced.

Operators who conduct the non-destructive tests in industry use six basic NDT methods: visual (VT), penetration (PT), magnetic-particle (MT), radiographic (RT), ultrasonic (UT) and eddy current (PT) [9]. Each of listed methods is characterized by some limitations, which are discussed in the article [12]. The current methods of NDT, for example, acoustic emission, thermography, vibrothermography, methods based on fibre optic sensors and their combinations with the conventional ones, are used for diagnosis of the particularly important objects. Usually, they are being conducted by the workers of research centres or specialized and accredited laboratories, which have the technical knowledge and necessary experience.

The authors conducted the preliminary tests that focus on the possibility of using the vibration diagnostics in welded joints testing. The descriptions of the test stand, testing methodology, and the results are presented in following chapters.

2. Method and the measurement conditions

The purpose of conducted work required constructing a stand that supports the vibrodiagnostic test on welded joints (Fig. 2). The structure of the test stand and its most important elements is shown in Fig. 2. During the process of preliminary tests, the plates were installed horizontally on the holder as it is presented in Fig. 1. The tests were conducted on four plates. The plate marked by number 0 was isotropic and did not have welded joints. The other three included welded plates that were marked by number: 2202 – the plate that did not have any incompatibilities, 2127 – the plate that had incompatibilities in the form of boundary bonding and 2132 – the plate with simulated crevice along the whole length.

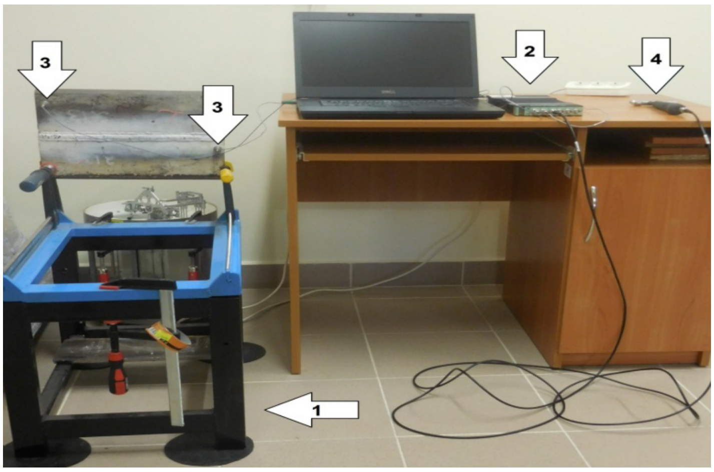

Fig. 2. The apparatus for welded joints, testing with vibration methods. The test stand includes: 1 – handler in which the plates (welded test pieces) can be installed horizontally – 4-point mounting or vertically – 2-point mounting, 2 – vibration analyser 3050-A-60 produced by Bruel & Kjaer, 3 – two accelerometers 4514-B, 4 – modal impact hammer (8206-002) with three interchangeable heads i.e. metal, silicon, and teflon

All test samples that have welded joints, were tested using the radiographic method before the measurement (Fig. 3). It enabled the assessment of the joints quality along with identification and placement of incompatibilities in the plates.

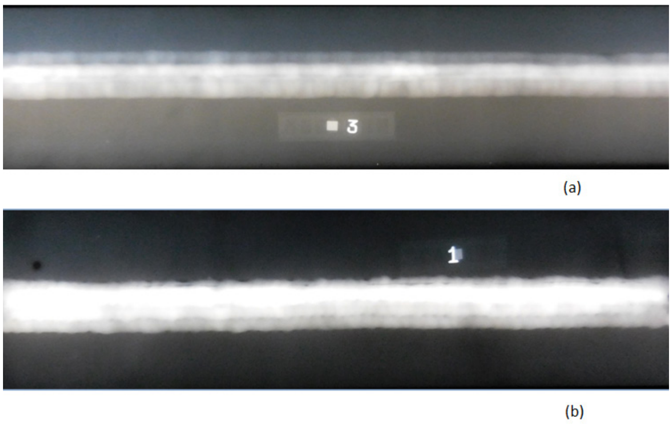

Fig. 3. Radiographic photography of welded joints where a) welded joint without faults (2202) and b) welded joint with incompatibility in the form of boundary bonding (2127)

The measurement of vibration generated by the plates was taken in the prepared test stand. The vibration was excited by the impact hammer with different heads: metal, silicon, and teflon. The places of strokes are presented in Fig. 4, described by means of *F1, F2,* and *F3*. The results were read by the accelerometers ACC1 and ACC2.

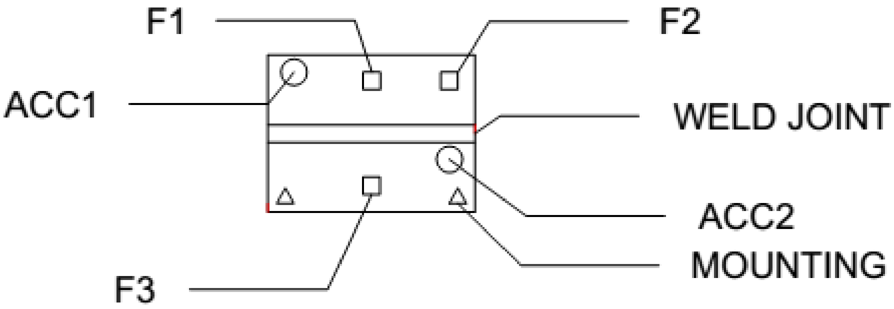

Fig. 4. Schematic diagram showing the arrangement of accelerometers (ACC1, ACC2), places of strokes (F1, F2, F3) and plates mounting places in the holders (Δ)

3. Time window method in time-frequency analysis

The time window method enables simulation of concurrent signal analysis in the field of frequency and time. This opportunity is often used in the analysis of technical systems dynamics, especially electrical or electronic ones. Much less often, it is used in mechanical systems testing. In case of time window method, the key element, which influences the quality of results, is a proper selection of the type and width of the time window. Then the FFT analysis (Fast Fourier Transform) is carried out for each of windows.

The time windows method was used in conducted tests in order to analyse the responses, which were recorded by accelerometers placed on plates with welded joints. The tests were done for rectangular window in terms of which various time intervals were checked. The decision to choose the rectangular window comes from the willingness to reduce the distortions of recorded course of response to the least extent. This kind of situation often takes place in case of windows that are more complex. Then at the cost of accepted changes introduced from the signal, it is possible to eliminate the part of distortions through the window.

Conducted tests aimed at the optimal coverage of spectrums characteristic changes, which determine the quality of welds and possible defects. Eventually, the chosen width of the window was 10 ms.

The examples of set of amplitude spectrums calculated for time windows are presented in Fig. 5 and 6. The first range covers the time windows from 1 to 12 and the second one from 10 to 21. The calculations were done for the plate without the weld and with different welded joints. The plate response to the signal made with a modal impact hammer with metal and teflon head was registered by accelerometer for all plates. Fig. 5 and 6 contain chosen results obtained for the metal head.

The comparison analysis of amplitude spectrums, calculated for each window, shows nonlinearities of structures of damaged welded plates. If the quality of welded joint is worse, the nonlinearities are stronger, that is when the defect is shown in the welded joint.

In presented example (Fig. 5 and 6), this kind of situation concerns on welded plate with the fault in form of boundary bonding. Moreover, the preliminary analysis of spectrums shows that most diagnostic information comes from first ten time windows, which mean about 100 ms of analysed response registered by accelerometer.

Amplitude spectrums presented in Fig. 5 and 6 are characterized by similar character of distribution, especially in terms of harmonics, however, important diagnostic information is given by the spectrum of higher harmonics, which analysis requires additional mathematical operations.

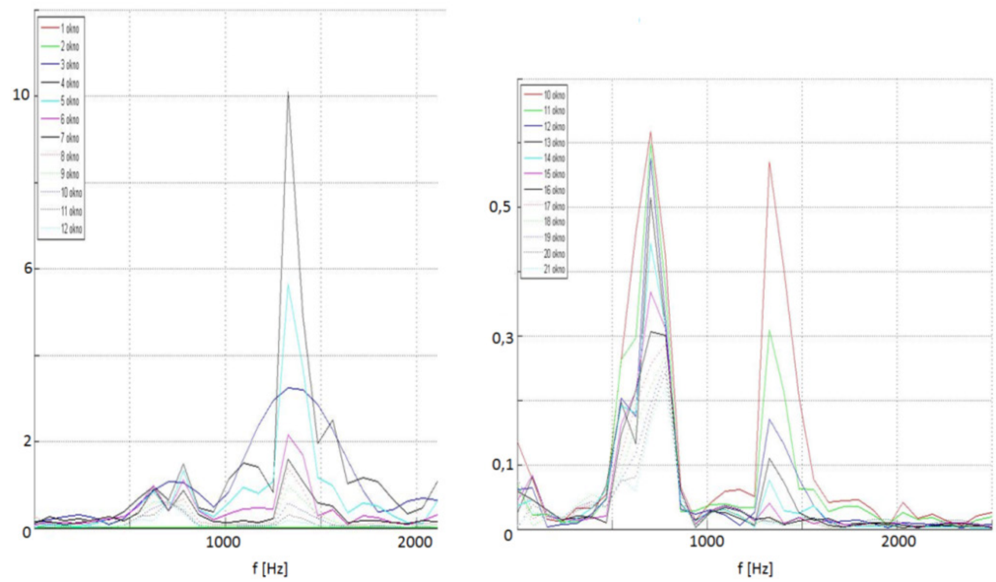

Fig. 5. Amplitude spectrums calculated by time window method for the plate without faults in the weld (2202)

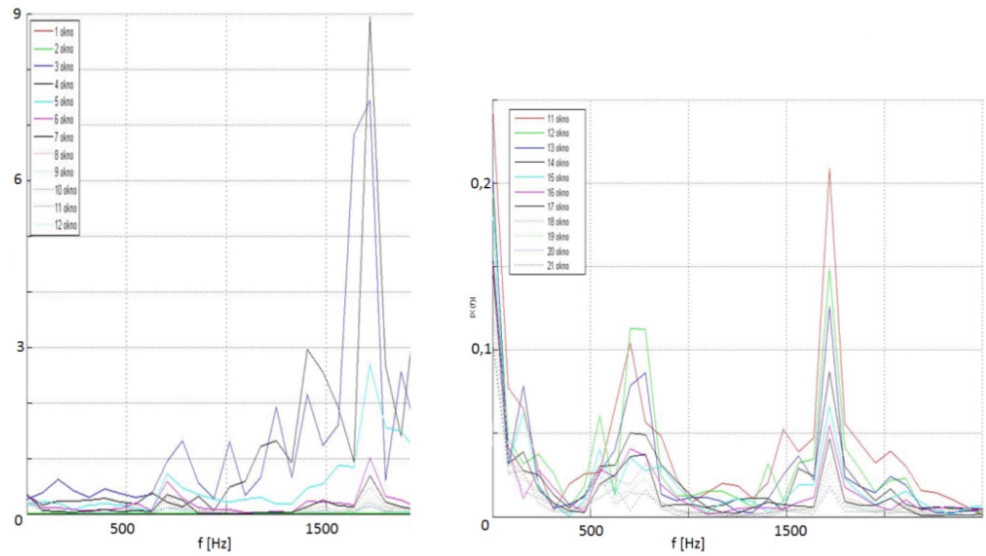

Fig. 6. Amplitude spectrums calculated by time window method for the plate with fault in the form of boundary bonding (2127)

4. Mean distributions of amplitude spectrums and their application to evaluate the welded joints

Proposed parameter to compare the amplitude spectrums calculated for each window of the same sample and to evaluate the nonlinearity resulting from welded joint in a plate was the mean. The mean is a measure of descriptive statistics, which was calculated from the equation (1).

$$|\overline{v}| = \frac{\sum_{i=0}^{N} |v(f_i)|}{N}, \tag{1}$$

where:

$|\overline{v}|$ – the mean of amplitude spectrum velocity calculated for the time window,

f_i – the frequency of i-th harmonic,

N – the number of harmonics.

The preliminary tests have shown that the analysis of only mean values is not enough. However, the relevant diagnostic information about the quality of welded joint is given by mean value distribution for the spectrums obtained from the whole response of time windows. Fig. 7 shows some examples of amplitude spectrums taken from chosen time windows and the values calculated for them.

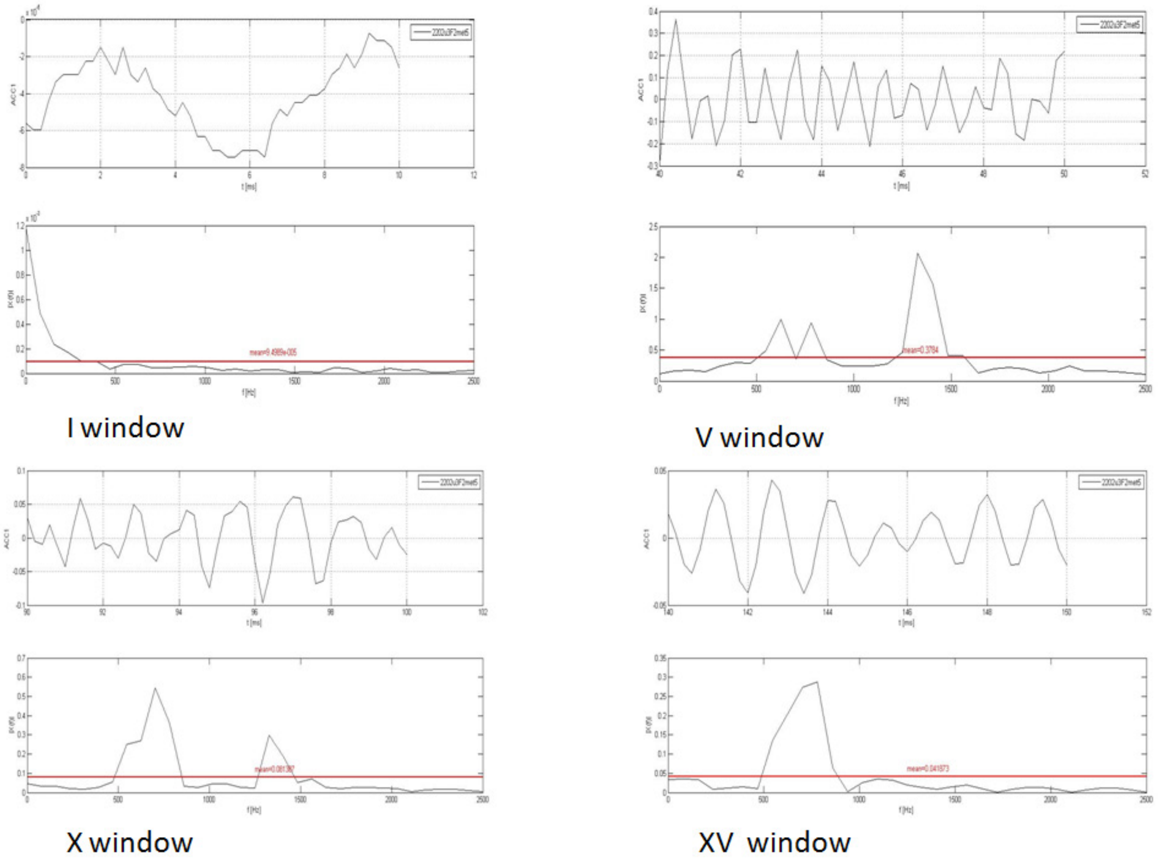

Fig. 7. Amplitude spectrums in chosen windows with the designated mean value

The distribution shown in Fig. 8, presents the alteration of the mean value calculated for the amplitude spectrum in given window in function of window number for a chosen welded plate. Presented characteristics show that the mean distribution for windows calculated for the sample without the weld (marked as number 0) differs significantly in comparison to mean distribution of other samples with weld or samples with a fault in welded joint (marked as: 2202, 2132, 2127).

This difference is especially applicable in terms of the level of mean values and cyclic value change between local maximums and minimums. It is also possible to notice that the mean value distributions for the samples with the weld and a fault are characterized by lower value than for the plates with weld and without incompatibilities.

5. Conclusions

The condition and quality of the weld joint for given plate can be obtained from diagnostic information of the mean value distribution analysis of amplitude spectrums calculated for the time window method. It is possible to use this parameter to detect some defects (cracks) in welds in systems made for autonomous SHM system. Because of similarities between presented characteristics and Poisson distribution, it is possible to introduce proposed method to evaluation of the welded joints on the basis of one parameter which would be expected value calculated for this distribution and marked as λ.

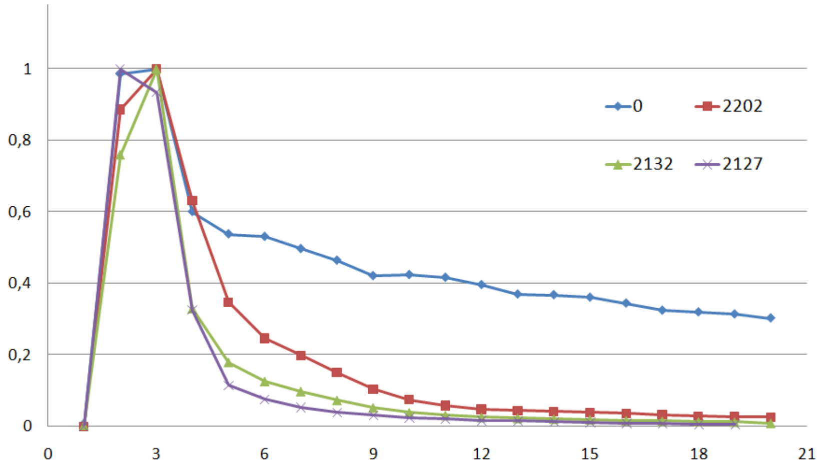

Fig. 8. Standardized distribution of mean value of the spectrums for windows in function of window number for tested plates, where: 0 – a plate without welded joint, 2202 – a plate with welded joint without a fault, 2132 – a plate with welded joint in form of the crevice, 2127 – a plate with welded joint in form of boundary bonding

Application of time windows method to evaluation of welded joints enabled the analysis of responses from accelerometers in the field of time and frequency. All differences of frequency characteristics in windows show the nonlinearity of the system and also additional dissipation of vibration energy, which is a sign of construction inconsistency. Additional dissipation means flawed welded joint.

Proposed evaluation method requires further testing of larger amount of samples with different faults in the welded joints.

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