ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1213753

ANALYSIS OF ABILITY TO DETECT DEFECTS IN WELDING STRUCTURES WITH USAGE OF DYNAMIC CHARACTERISTICS SPECTRUMS

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Abstract

Non-destructive methods of testing (NDT) welded joints are nowadays intensively developing due to their numerous advantages. The most significant of them are the possibility of objects diagnosis in the place of their work without the necessity of disassembling or long outage, lower costs of realization as well as considerably lower insalubrity for people conducting the tests. Study of dynamic characteristics of welded elements creates a good possibility for welded joints assessment in comparison to other known non-destructive testing methods. The main reasons are Fourier analysis (FFT), damping analysis, differences in signals or their answers. Presented method can be used in classical NDT tests as well as in structural health monitoring (SHM). Assumptions for quality evaluation methods of welded plates using spectrums analysis of dynamic characteristics are presented in the article. In order to provide the high quality of research, the measuring devices of Bruel & Kjaer Company are used. Both, the testing methodology and possibility of using vibration method in welded joints testing are presented. The attention is also drawn to the vital testing elements like proper selection of impact hammer ending and impact place as well as the problem of repeatability of diagnostic signals. The value of repeatability of obtained signals will be of critical importance in the comparative method, which is under development. The results of initial testing of plates with proper and faulty welded joints have been analysed. Among welding faults, the boundary bonding and crevice have been considered. The analysis of impact hammer dispersion values in correlation to the spectrum of dynamic characteristic has been conducted. Statistic methods have been used for the assessment.

Keywords: *diagnosis, welded joints, non-destructive testing, NDT, SHM, vibrations, spectrums analysis, accelerometers*

1. Introduction

Non-Destructive Testing NDT is the kind of testing which allows obtaining 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 joints that were welded, adhesive-bonded, soldered, to castings, and to the elements made of composite material [2, 5]. They are used in the reliability assessment procedures and in the assessment 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. It is used in the industry and in the laboratories of research centres during a designing process and while defining the properties of new materials. It enables the evaluation of joints without interfering in their structure [2]. The possibility of identifying 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 is that it gives an opportunity to define the properties and obtain a physical description of tested material [3, 12].

The control activities that ensure the quality of the welded joints take place, not only during the production process but also, in order to diagnose the exploited structure. Their aim is to avoid unexpected damage of technical objects by excluding the objects having some exploitation damage that jeopardizes the safety during the further usage. The failure to perform 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, 9].

The modern systems for Structural Health Monitoring SHM are based on NDT, which are used during the periodic inspections of welded structures at places where the occurrence of defects is the most likely. The main difference between SHM and NDT results from hardware architecture [8]. 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 crucial 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 [8, 9].

There are many factors, which influence fast development and wide use of NDT in technology. The most important are safety and economics. The issues that are connected to safety determined the routine use of non-destructive methods in aviation, astronautics, extractive industry, nuclear power, and shipbuilding industry. The economic balance fully justifies the necessity of NDT in mass and large-scale production. In the dynamic 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 information about them. Such development strives to achieve the increase in execution speed and in safety as well as reducing harmful effects of used resources on operator's health. The development concerns currently used methods and the ones that have just been introduced.

Nowadays, the operators who conduct the non-destructive tests have a wide range of approaches, which, along with technology development, are supplemented by new methods. Currently, the common use of hybrid research becomes a standard. This research uses mixed methods that combine two or more NDT methods. This procedure allows extending the usage and increasing the accuracy of obtained results. Hybrid methods are divided into two groups: the ones that use the same physical phenomenon and others that operate on the principle of complementarity of particular test methods [13]. The example of hybrid method that uses the same physical phenomenon is the combination of acoustic emission and ultrasonic testing. When analysing the analogical physical phenomena (generating the mechanical waves) and equipment (piezoelectric sensors and electronic oscillator, check charts), there is the possibility of continuous, exploitive diagnosis of tested element. Such diagnosis allows detecting generation of new defects (using the acoustic emission) along with the development of the ones that have already been diagnosed (using the ultrasonic testing) [6]. The thermographic examination may be presented as the exemplary of hybrid method that operates on the principle of complementarity of particular test methods. The thermographic examinations may be used as a combination of hybrid methods, which use physical phenomena of ultrasonic vibration, eddy currents or radiation (thermal, light, microwaves) [4]. The example of commonly used combining hybrid methods is surface testing combined with radiographic and/or ultrasonic examination.

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) [7]. Each of listed methods is characterized by some limitations, which are discussed in the article [10]. The current methods of NDT, for example, acoustic emission, thermography, vibrothermography and the combinations of these methods with the conventional ones, are used for diagnosis of the particularly significant objects. Usually, they are being conducted by the workers of research centres or specialized and accredited laboratories who have the technical knowledge and necessary experience.

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

2. Test stand

The test stand for the welded joint testing that uses the vibration method was prepared at the faculty of Marine Engineering at Gdynia Maritime University. The setting of the stand and its components are presented in the Fig. 1. The stand includes the holder which can be used to install the plates (welded test pieces) horizontally – 4-point mounting or vertically – 2-point mounting, vibration analyser 3050-A-60 produced by Bruel & Kjaer, two accelerometers 4514-B, modal impact hammer (8206-002) with three interchangeable heads i.e. metal, silicon, and Teflon.

During the preliminary tests, the plates were installed vertically in the holder as Fig. 1 shows. The tests were conducted on four plates. One of them was marked as number „0". It was made of homogenous material that did not have a welded joint. The other three plates were welded and had the following numbers: 2202 – the plate that did not have any incompatibilities, 2127 – the plate that had incompatibilities in the form of boundary bonding, 2132 – the plate with simulated crevice along the whole length.

Firstly, all test pieces that have welded joints were tested using the radiographic method. It enabled the assessment of the joints quality along with identification and placement of incompatibilities in the plates.

Fig. 1. Test stand for testing of welded joints with use the vibration methods

The measurement of vibration generated by the plates was taken in the prepared test stand. The vibration was caused by the impact hammer with different heads: metal, silicon, and Teflon. The places of strokes are presented in Fig. 2, described by means of F1, F2, and F3.

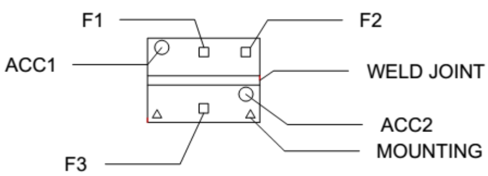

Fig. 2. Schematic diagram showing the arrangement of accelerometers (ACC1, ACC2), places of strokes (F1, F2, F3) and plates mounting places in the holders (Δ)

3. Research methodology

The developed procedure was applied to take the measurements of selected plates on the test stand. The plates were installed stiffly and vertically in the mounting holder (2-points mounting). The holder was placed on the flat surface. It was taken into consideration, to perform the comparable precision during tapping the plate with the impact hammer. While taking the measurements, the accelerometers measured the speed and time, and the impact hammer was used to register the force of strokes. The data that was collected during taking the measurements was analysed in MATLAB.

Reference [11] presents the analysis which aim was to determine the optimal place of stroke and choosing the most beneficial kind of impact hammerhead. The analysis was conducted using the calculated spectrums FFT (Fast Fourier Transformation). On the basis of spectrums comparison for plates: homogenous – not having any incompatibilities, with incompatibilities – like boundary bonding and plates with simulated crevice along the whole length, it was claimed that conducting non-destructive tests of welded joints with vibration method generates crucial diagnostic information that enables making assumptions about the state of welds.

By comparison of spectrums for different plates which were tested with heads: Teflon, metal, and silicon, it is possible to state that the most comparable results are obtained with metal and Teflon head. On the other hand, the spectrums obtained for silicon head are characterized by high level of fluctuation for low frequencies. Contrary, the spectrums of metal and Teflon head are regular and characterized by gains only in case of relevant harmonic.

Conducted analysis enabled identification of the places of strokes for impact hammer, which give the best results. Fig. 2 presents initially proposed stroke places: F1, F2, and F3. The comparison of spectrums for measured plates shows that the best place for testing, among selected ones, is F2 position on welded plate.

Therefore, this research may be considered as the introduction for further work. After assessing the types of impact hammer heads and the place for measurement on the welded plate, answering to one question became crucial: to what degree does dispersion of place and force of stroke, made by impact hammer, influence the vibration and thereby, characteristics of spectrums?

The answer to this question is particularly significant in the context of developed comparative method which aim will be to assess the quality of welds and to identify the incompatibilities.

Figures from 3 to 6 present the spectrums made for five strokes with metal and Teflon head. These spectrums are made for a homogeneous plate and the plate without any faults in weld seam. Given figures show that the dispersion and force of stroke influence the shape of spectrums. Accordingly, the previous question should be elaborated and another one should be asked, i.e.what should be the accuracy of two or three strokes, made with impact hammer, to enable comparison of obtained spectrums?

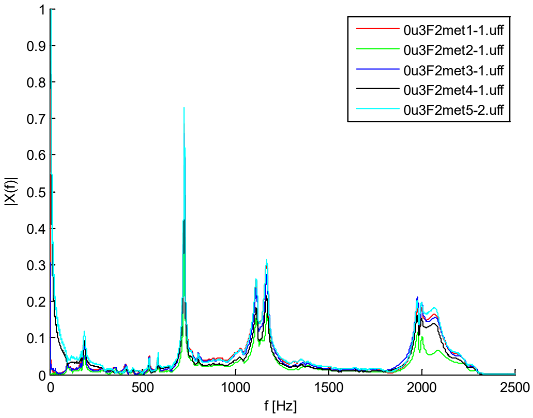

Fig. 3. FFT (ACC1) for five strokes made with metal head in impact place F2 for the homogenous material plate

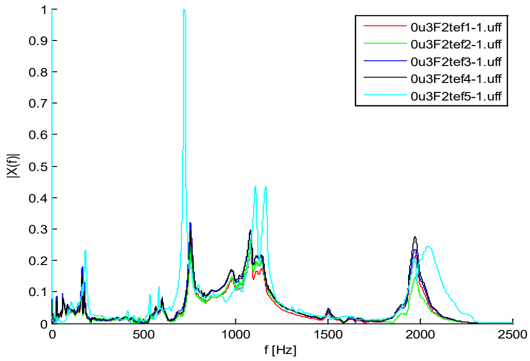

Fig. 4. FFT (ACC1) for five strokes made with Teflon head of impact hammer in impact place F2 for the plate made of homogenous material

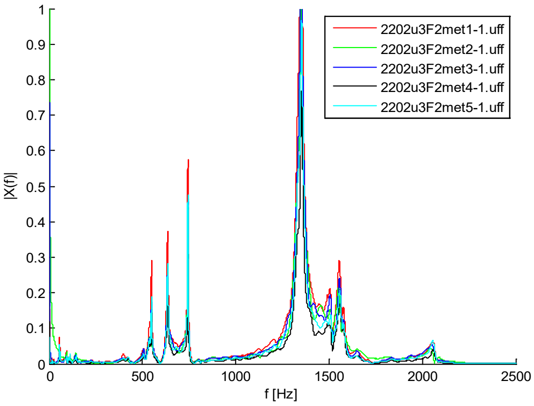

Fig. 5. FFT (ACC1) for five strokes made with metal head of impact hammer in impact place F2 for the plate without any faults in weld seam

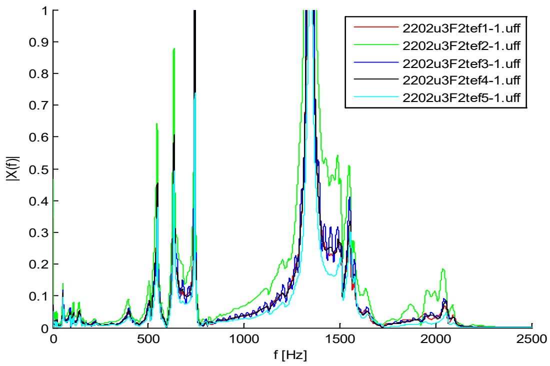

Fig. 6. FFT (ACC1) for five strokes made with Teflon head of impact hammer in impact place F2 for the plate without any faults in weld seam

4. The analysis of dispersion of a stroke made by impact hammer

The dynamic characteristics spectrums analysis using the statistical methods was conducted to assess the acceptable dispersion of stroke made by impact hammer. The analysis concerned the calculated spectrums for homogenous plate and the plate with the weld without faults in seam, which are presented in Figs. 3-6. The calculations were done for the results obtained for the type of plates like those that the ones described above because they were considered more representative.

While measuring the vibration characteristics for tested plates, the coordinates of impact hammer strokes were noted. For the purpose of analysis, the coordinates of stroke were normalized in the way that allowed designating the circuit, which represents the dispersion. The measurement was repeated five times i.e. for each hammer head and two types of plates. Secondly, the descriptive statistics were used to compare the spectrums characteristics. The comparison was made on the basis of mean value (M), standard error (Se), median (Me), standard deviation (Sd), skewness (Ske), minimum value (Min) and maximum value (Max). Such set of descriptive statistics enabled comparison the spectrums characteristics, in terms of both frequency and the amplitude module. Tab. 1 and 2 present the values of descriptive statistics.

Tab. 1. Descriptive statistics for a homogenous plate – 0u3F2met and 0u3F2tef

termination		M	Se	Me	Sd	Ske	Min	Max
Teflon	1	0.043	2.86E-04	0.020	0.052	2.041	8.15E-07	0.255
	2	0.044	2.82E-04	0.022	0.051	1.734	1.65E-07	0.263
	3	0.053	4.94E-04	0.025	0.063	1.627	6.95E-07	0.322
	4	0.054	5.04E-04	0.025	0.064	1.647	1.10E-06	0.297
	5	0.076	6.15E-04	0.038	0.111	5.098	3.41E-07	1.502
metal	1	0.046	3.38E-04	0.023	0.061	23.478	7.98E-07	0.856
	2	0.025	1.86E-04	0.013	0.034	4.166	7.36E-07	0.403
	3	0.043	3.19E-04	0.021	0.058	3.539	3.32E-07	0.658
	4	0.047	7.40E-04	0.023	0.189	36.912	4.32E-07	11.492
	5	0.064	1.41E-03	0.033	0.256	36.826	6.57E-06	15.883

Tab. 2. Descriptive statistics for welded plate without faults in the seam – 2202u3F2met and 2202u3F2tef

termination		M	Se	Me	Sd	Ske	Min	Max
Teflon	1	0.094	1.29E-03	0.027	0.234	55.043	8.701E-07	2.687
	2	0.173	2.32E-03	0.052	0.420	6.526	1.926E-07	4.808
	3	0.100	1.34E-03	0.028	0.242	5.876	6.368E-07	2.481
	4	0.095	1.29E-03	0.027	0.234	6.457	7.201E-07	2.654
	5	0.068	1.28E-03	0.019	0.164	6.066	4.150E-07	1.793
metal	1	0.060	7.96E-04	0.016	0.144	43.103	2.127E-06	1.506
	2	0.053	5.30E-04	0.017	0.136	12.439	2.946E-07	5.424
	3	0.051	6.70E-04	0.015	0.121	5.946	2.476E-07	1.280
	4	0.032	4.14E-04	0.009	0.075	5.507	2.283E-07	0.767
	5	0.042	5.44E-04	0.012	0.098	5.410	1.046E-06	0.966

Assuming that conditions during taking measurement were the same, the main difference between calculated spectrums characteristics for subsequent repetitions results from place dispersion and the force of the stroke. Change of stroke causes different manner of inducing the vibrations and consequently the difference in their spectrum. On the basis of presented descriptive statistics, it is clear that the spectrums differ from one another. The differences are greater if the place of stroke was modified significantly during its repetition.

Figures 7 and 8 present the concentration place of stroke represented by mean value and median. On the basis of statistics value, it was determined that the acceptable dispersion of place of stroke which, satisfactorily facilitates obtaining the repeatability of the measurements, is a point whose diameter equals 0.5 cm. The points that fulfil this requirement are circled in Fig. 7 and 8.

5. Conclusions: dispersion analysis of impact hammer stroke

Conducted research shows that performing non-destructive tests for welded joints with vibration method generates diagnostic signals that enable making assumptions about their state and quality. Authors plan to conduct further tests using metal and Teflon head at stroke point F2 and with different placement configuration of accelerometers.

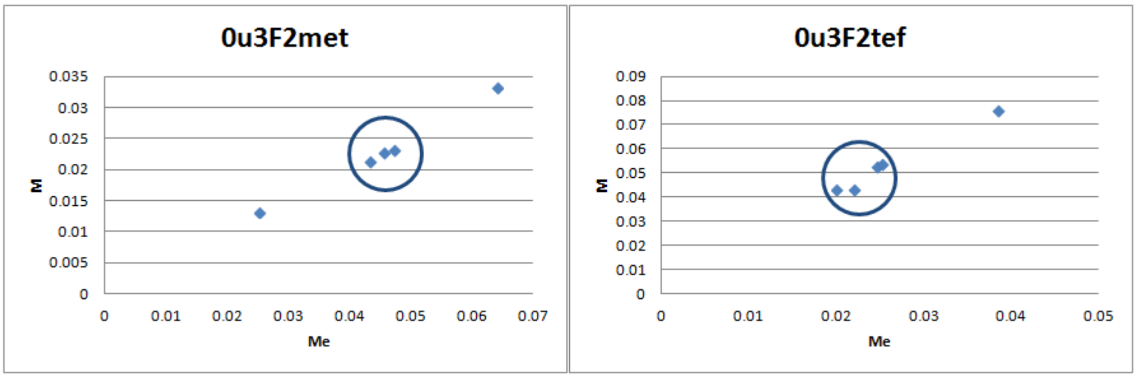

Fig. 7. Dispersion of impact hammer stroke for a homogenous plate

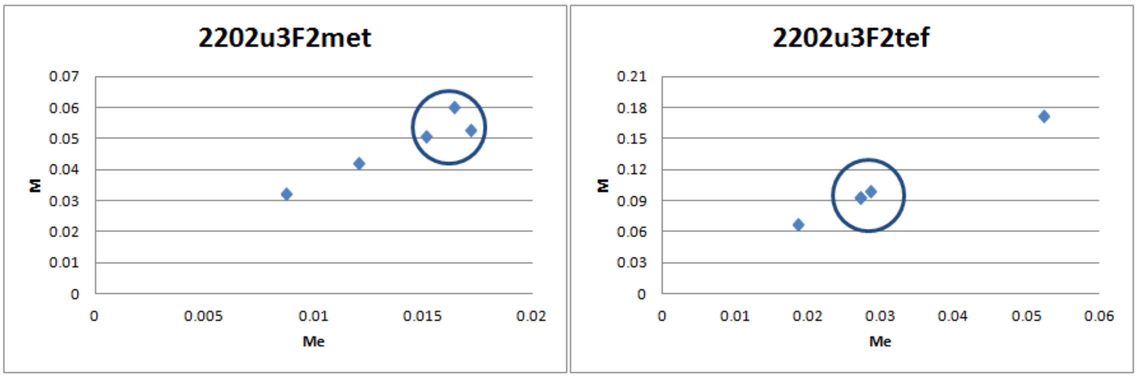

Fig. 8. Dispersion of impact hammer stroke for a welded plate without faults in a seam

On the basis of conducted analysis of place dispersion and force of impact hammer stroke, it may be assumed that the precision, in case of willingness to obtain repeatable spectrums for dynamic characteristics, is crucial. In respect of developed comparative method, which will be used to assess the quality of welded joints, it is a key element contributing to its application and subsequently, to identification of incompatibilities in weld seams.

The feature that distinguishes proposed method of non-destructive testing from other methods is the possibility of its application to all materials and their joints (e.g. metals, pottery, composite). The second asset of this method is the ease with which the system assessing vibration can be applied in production line. In the future, this solution will enable fast quality control of manufactured products.

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