ANALYSIS OF ACOUSTIC DIAGNOSTICS ERRORS OF STRESS STATE FOR SHAPED PROFILES OF METAL STRUCTURES

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Abstract

The article is devoted to analysis of the errors that occur when acoustic diagnostics of stress state for shaped profiles of metal structures. The analysis of methods for acoustic diagnostics of stressed state of shaped profiles was conducted using mirror-shadow method and areas, causing the occurrence of errors, were revealed. The analysis of tool, methodical and subjective errors that accompany acoustic diagnostics of stress state of shaped profile allowed offering recommendations for their reduction and increasing the reliability of diagnostics results. The necessity of reducing the total error for determining the stress state caused by factors accompanying acoustic diagnostics of shaped profiles was shown. Application of automation during the acoustic diagnostics of stress state for shaped profiles of metal structures was proposed. This will significantly increase the reliability of the data by reducing human intervention in the process of measurement and processing results. Technical and methodological solutions were proposed that will reduce the impact of the total error on the result of acoustic diagnostics of stress state for shaped profiles using the mirror-shadow scanning method.

Keywords: total error, acoustic diagnostics, stress state, shaped profiles.

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1. Introduction

Demand for the use of metal structures (MS) as the main structural elements is increased in conditions of modern building in Ukraine. Buildings, which main structural elements are MS, may be shopping malls, shops, showrooms, technical centers, warehouses, factories, workshops, sports complexes, parking lots, and more. Metal structures made from rolled or welded shaped profiles (SP), which ensures the integrity, reliability and durability of industrial buildings [1].

SP MS are bending. Occurrence of maximum values of stresses is observed in areas of maximum deflection. Acceptable values of loads that don't give rise to any critical stress in areas of maximum concentration are calculated to ensure the reliability of the MS design. However, the change of the MS stress state (SS) of the building can be caused by several factors, such as: change of the building purpose; reorganization of technological process with a change in equipment of production lines in the same building; operation of the building outside project regimes; natural disasters; changing regulatory requirements for buildings.

To ensure the integrity of the building it is necessary to control the technical state of buildings and determining the values of stresses in the areas of their concentration. Therefore, it is particularly important to develop operational methods of nondestructive testing that will diagnose SS SP values with high accuracy throughout the life cycle of the building.

Widespread use to stress diagnostics in metal elements such elements as pipes, rails, rims of railway wheels, oil pipelines, etc. received acoustic diagnostic methods that don't require complex methodological support and allow determined using directly proportional relationship of metal SS by changing the velocity of ultrasonic waves [2–4].

2. Materials and Methods

Velocity of ultrasonic waves in MS structural steels affects not only the chemical composition of the metal and the quantitative value of the individual components, but also manufacturing technology, the use of heat treatment that change the structural and textural anisotropy [5]. Therefore, using ultrasound diagnostics it is necessary to assess the relative value of the wave velocity in different parts of the control object (CO). Thus, to ensure the accuracy of diagnostics results it is essential that the measurement error is much less for variations in the velocity of ultrasound that is due to metal anisotropy.

The aim of this article is to conduct a comprehensive analysis of errors that occur during acoustic diagnostics of SS SP MS, which will make recommendations to the means to reduce them.

Mirror-shadow method is selected for acoustic diagnostics of SS SP. This method unlike other [2–4] allows diagnosing SP MS that are parallel and inclined internal face. The method is implemented with excitation voltage pulse duration of 0.5 ms with amplitude of 300 V at a frequency of 5 MHz. Ultrasonic wave (UV) is transmitted at an angle to the CO material, that it excites transverse waves and reflected from the opposite wall and accepted the same contact converter. Measuring geometric characteristics of the product and measuring time of UV passage are used for this method. As a method of measuring the UV velocity is an indirect measurement because the fault detector is measured directly of UV passage along the CO scanning base, so it is reasonable to measure the time of UV passage, increasing the accuracy of the results [6].

To assess the reliability of the results it should theoretically and experimentally evaluate all components of the error and find the value of total error for a particular law [7, 8]. Analysis of factors affecting the measurement result will highlight the significant and insignificant, which can be neglected. It also will identify errors, which can be influenced by the use of various kinds of technical, design, methodology and other decisions and errors that can't be eliminated.

3. Results

The errors that accompany the process of ultrasonic diagnostics include [6–9]:

1. Instrumental measurement error that is due to the imperfection of the means measuring the time offset between emitted and accepted ultrasonic signals and precision of micrometer tool.

2. Methodological measurement error that is due to the imperfection of the chosen method of measurement. It may include errors caused by the difference between the accepted model of the measurement object and a real object, imperfect way of measuring time delays, inaccuracies of mathematical model using in finding the actual tension, making inaccurate CO that may lead to inconsistencies of base size and size of acoustic path of piezoelectric converter (PEC).

3. Subjective error that is due to insufficient qualifications or individual characteristics of the operator performing the measurement. Also influencing factors related to instability of acoustic contact, inaccuracies of mounting converters to each other and the force of pressing CO to PEC, which affects the thickness of the layer of contact liquid.

Considered classification of types of errors that accompany the process of ultrasonic diagnostics is generally known, however, using different scanning methods and CO, factors that lead to the appearance of each of them are original. Therefore, to determine the total error that occurs when acoustic diagnostics of SS SP MS and finding ways to reduce it is necessary to analyze the factors affecting the occurrence of each of these errors (**Fig. 1**).

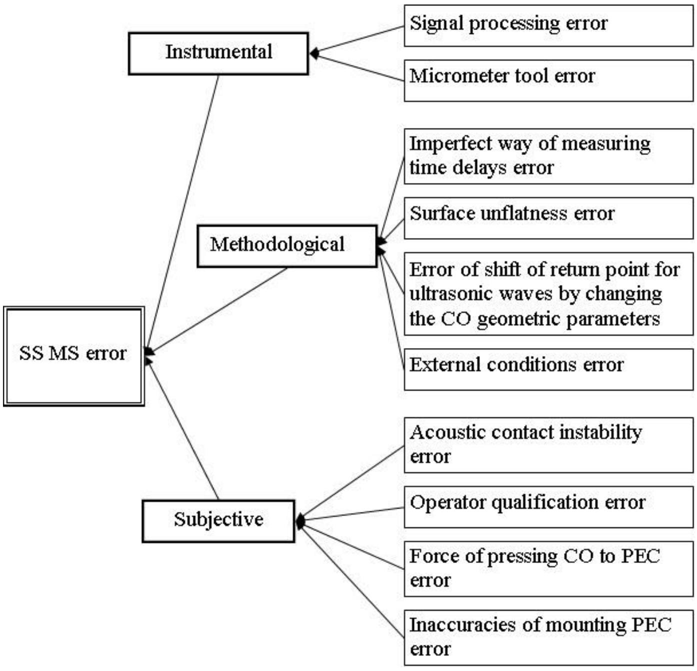

Fig. 1. Factors affecting the accuracy of SS SP MS

3. 1. Analysis of the impact of instrumental error

Instrumental error is a part of measurement error caused by imperfection of measuring tool: difference of the real conversion function of device from its calibration dependence, inherent noise in the circle of measurement, delay of measuring signal as it passes in the measuring system, internal impedance of measuring system, inaccuracies of adjustment and making measuring devices, aging and so on. Instrumental measurement error is divided into basic (measurement error in the application of measurement tools in normal conditions) and additional (component of measurement error resulting from the rejection of any influence quantities of its nominal value or overranging beyond the normal range of values).

Factors affecting the instrumental error of SS CO are shown in **Fig. 2**.

Instrumental errors caused by equipment precision that is used to SS SP MS diagnostics include: time delays measuring error and micrometer tool error.

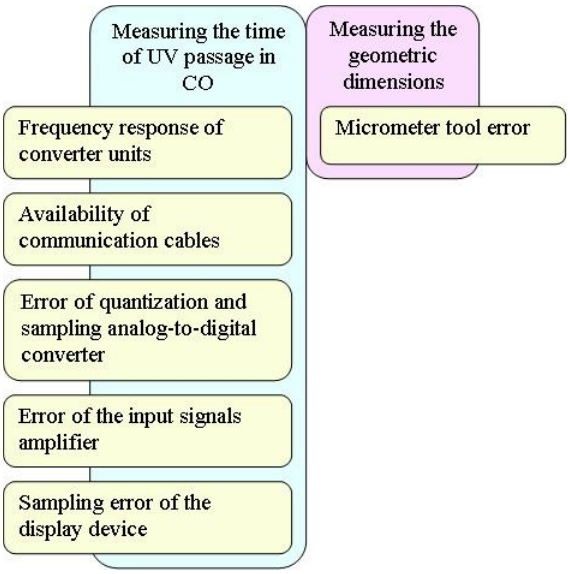

Fig. 2. Factors affecting the instrumental error depending on the area of origin

Instrumental error of device (such as calipers or a micrometer) that used to determine the linear size indicated on the device in the form of absolute error or is calculated based on the measuring sensitivity. In the absence of accuracy class and absolute error, it is assumed to be half measuring sensitivity. Method for determining errors for devices with digital display of measured values is given in the passport of the device and in the absence – the absolute error is half the average digital level of the indicator.

To measure the SP geometric dimensions is not possible to use calipers or a micrometer for the reason that access to CO can be limited: some beams hidden by overbuild decorative or other constructions, profile wall is often welded with other SP MS and more. Also, the main difficulty is the construction of beams, which limits access to the wall profile. Therefore, it is possible to use only ultrasonic thickness gauge, allowing controlling with access to the CO on one side. Therefore, ultrasonic thickness gauge for sheet metal TM-8818 (**Fig. 3**) with a measuring range of 1.0 to 50.0 mm and an accuracy of ±0.01 mm is selected. Thickness of measured CO SP elements, starting from 4.2 to 23 mm for wall and from 4.8 to 35.5 mm for the shelves (according to the standards of Ukraine GOST 26020-83, GOST 8239-89, GOST 19425-74, GOST 8240-97). Hence limits the relative error when measuring the thickness value with measuring sensitivity 0.01 mm is ±(0.04–0.2) % and ±(0.02–0.2) %, respectively. This shows the permissibility of the use of the micrometer tool to solve this problem because it caused the error is less than 1 %.

Fig. 3. Ultrasonic thickness gauge for sheet metal TM-8818

Accuracy of measuring time intervals (oscilloscope) is determined by the quality of measuring and amplifier channels. It is under the influence of frequency bandwidth of amplifier, linearity and stability of measuring time intervals, sample rate and bit of analog-to-digital converter (ADC) and more. Random error of ADC today by increasing the bit (12–16 bit) and sample rate (hundreds of megahertz) can be minimized (less than 0.1 %), and systematic is adjusted by calibration software [6].

Physical and mechanical properties of piezoceramic converters and manufacturing quality of the sensor are affected on the measuring results. This effect is manifested by distortion of the recorded pulse signals. It is known that the piezoceramic converters are characterized by energy dissipation in the material and their own acoustic nonlinear distortions [10]. Therefore, converters should be broadband and have a uniform frequency response (FR) for this task.

The amplifier errors are: instability of transfer ratio, zero drift, FR impact on waveform, etc. [11].

The main parameter of equipment evaluation is determination of error, which it makes for result of solving the problem. Relative error of SS determination for SP metal, such as steel S245 GOST 27772-88, with the permissible absolute error of measuring time intervals is estimated. To ensure the accuracy of diagnostic results it is necessary to ensure accuracy within 3 %. This suggests that it is necessary to determine the time of the acoustic wave passage within 1 ns. As the equipment to ensure the required accuracy is selected digital oscilloscope SIGLENT SDS1202CNL +(China) with 200 MHz bandwidth and sampling rate in real time 2 HS/s, which allows to determine time intervals with a specified precision that is quite satisfactory.

In general it can be noted that the chosen micrometric tool for measuring geometric dimensions and device for measuring time intervals can provide listed above accuracy that is satisfactory for use SS SP MS acoustic diagnostics. Therefore, the influence of instrumental error on the result of SS control will be minimal.

3. 2. Analysis of the impact of methodological error

Methodical error is caused by imperfection of chosen method of measurement, accepted model of measurement, method of application of the measuring tool, algorithm for calculation of measurement results and other factors that are not related to properties of measuring tools. Methodological error can't be specified in the regulatory and technical documentation for a measuring device because it is independent and should be determined in each case by special studies (measuring diagram analysis).

The main factors affecting the appearance of methodological errors in determining the SS MS are shown in **Fig. 4**.

The roughness of the surface, the impact of external conditions such as temperature, humidity, etc., affect both in the measurement of geometric dimensions and in measuring the time of UV passage. Using the measurement system it must take into account the state of the CO surface, because most accurate results can be obtained only when the transmitted and accepted surfaces are smooth and free of external defects. Thickness of control increases due to reverberation of ultrasound in a thick layer of liquid contact in the case of rough surface [11].

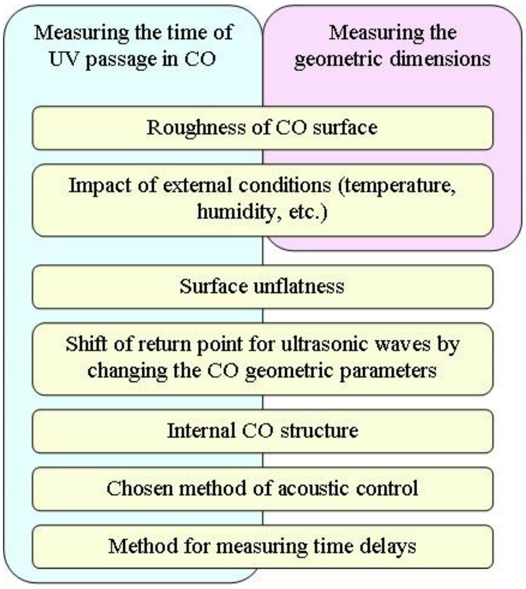

Fig. 4. Factors affecting the methodological error depending on the area of origin

Effect of changes in humidity, temperature, pressure, presence of vibrations, electromagnetic fields and various kinds of radiation causes errors. Thermal expansion of the material can cause error of measurement of geometric parameters and time of ultrasound passage. There is a change in the velocity of UV passage when the CO temperature is changed. This option takes into account using the introduction of the adjustment factor that takes into account the thickness and density of the contact liquid, force of pressing converters to the control object, the angle of ultrasonic wave transmission and material of control object.

Unflatness of CO surfaces, faces of beam profile shelf, leading to that arrival point for ray may extend beyond PEC. This means that the received signal is not formed by the main ray, but by side ray, and will affect the amplitude of the signal and its path. Accuracy of ray displacement is offset by position adjustment of receiving converter.

Shift of UV arrival point when changing CO geometric parameters is occurred when external load is exposed to it. During the tension there is a thinning of beam shelf, but during compressing – its thickening, leading to the change of UV display point and its arrival with the offset to the calculated center. However, shining mix is in the small size and less than 2.5 % of the half-side of piezoelectric converter element [12].

The impact of the CO internal structure provides anisotropy in the diagnostics area that related to the method of profiled metal manufacture, distribution of internal stresses, presence of residual stresses in the neutral profile line. Anisotropy for profiles of hot-rolled material is 2–2.5 % [5]. During measurements it takes into account the relative importance of time of UV passage in a tense shelves and profile wall, taking into account the fact of anisotropy. The presence of defects in the material structure lead to inaccurate measurement pulse passage time or lack of measurement results, because the signal after reflection from the defect have a different path and doesn't come to the receiver.

3. 3. Analysis of the influence of subjective errors

Subjective error or operator error is caused by insufficient qualifications or individual characteristics of the operator performing the measurement and related to carefully implementation of rules for measuring. This error is much less when using automatic or automated measuring instruments. Most of subjective errors relate to the accident, but some of them related to the individual operator, can be systematic.

The main factors [6] affecting the subjective error in determining SS SP MS are shown in **Fig. 5.**

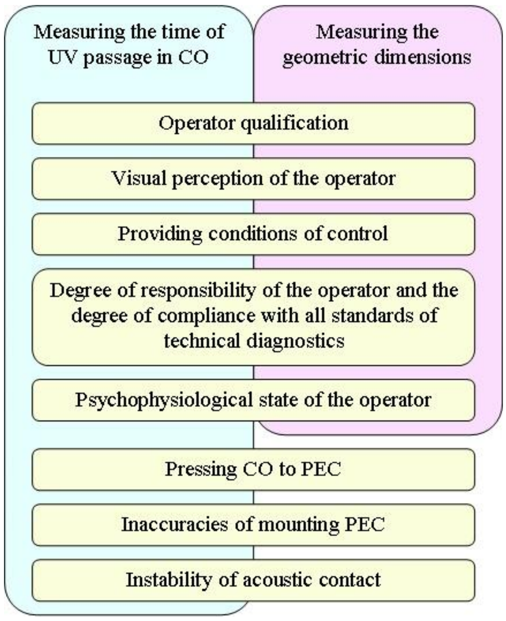

Fig. 5. Factors affecting the subjective error depending on the area of origin

There are four types of subjective errors of operator actions:

– reference error (especially important when provided with measurement error not exceeding the measuring sensitivity);

– presence error (manifested as influence of thermal radiation of operator on ambient temperature, and thus a means of measurement);

– action error when the operator setting devices, carrying out measurements, evaluating roughness of control surface;

– professional errors that connected with qualifications of operator, its respect to measurement process, its understanding of the fundamentals of the acoustic control and diagnostics.

Personal (subjective) or reference errors depend on the individual operator. Such errors are reduced with increased operator training and improvement of readout devices.

Providing conditions of control is meant organizing the workspace for the control, surface preparation for measurements, and comfort of the workplace.

During manual control it is possible to establish a significant pressing effort of converters to CO, leading to a change in thickness of contact liquid and amplitude of acoustic pulse, which is emitted in CO. In addition, the contact layer thickness will be determined by viscosity and capillary properties of material, which is used to provide acoustic contact. Thus, thickness of the contact liquid will vary within certain limits in different measurement points on the CO surface at different times; even in one and the same point on the CO surface using returnable measurement at different times it is impossible to ensure stability of thickness of the contact liquid for manual control. Obviously, this component is random. It is necessary to know the law of its distribution and tolerances for its accounting [6]. The radical measure to correct this error is to develop the block of converters that will allow constant contact of converters with CO surface, their pressing, thickness of the contact layer and a positioning of receiving and emitting converters relative to each other. Thus, this error is systematic in nature. This makes it easy to avoid it by introducing relevant amendments in the calibration.

Roughness of CO surface using the contact scanning method has a major influence on the UV velocity. It is necessary to measure the CO surface roughness parameters to establish its value within according to [13]. This will reduce the influence of subjective errors in diagnostics.

Roughness measurement should be made towards scanning. Surface roughness should be less than the size of the error in the calibration of CO-2. Thus, the roughness standard sample CO-2 Rz15 and error towards scanning ±0.02 mm, surface roughness didn't significantly affect the overall error of time of UV passage [14].

The main recommendation of the terms of diagnostics and leveling error of 1 % should provide a CO surface roughness in PEC mounting area less than 40 microns or less Ra2.5 [15].

The main directions in combating subjective error are the development and implementation of methodological and engineering innovations. Together they can develop specialized control techniques using automated systems and provided the necessary sensitivity control [6].

Automated system and special construction of block of converters will control the pressing force of converters to CO, which will stabilize the thickness of contact liquid and therefore more accurate accounting of its impact on results of measurements.

Using the automated system, some components of subjective errors then can be attributed to the source of the methodological errors, and as for the nature of manifestation – the systematic errors that greatly facilitate their accounting and compensation.

4. Conclusions

The use of automation during SS SP MS acoustic diagnostics will significantly increase the reliability of the results by reducing human intervention in the process of measurement and processing results.

The following solutions are suggested to reduce the effect of total error on diagnosis result:

– to develop a block of converters that provide continuous pressing converters to CO and layer thickness of the contact liquid between and the prism of converters and CO surface, considering the accuracy of positioning;

– to reduce the impact of error related to the positioning of converters relative to each other to provide accurate positioning through design solutions for block of converters that will be the next topic of discussion.

Conducted theoretical study of errors of acoustic diagnosis indicates the possibility of its use to determine SS SP MS during the operation.

So, determined actual stress as compared to structurally valid, can estimate current conditions of metal structure, evaluate efficiency and draw conclusions about the necessity for further action to change conditions. Thus it is possible to establish the degree of accident for buildings and immediately state of metal in structural elements.

Using this method allows to perform with appropriate grounds survey and evaluation of the technical state of metal structures in a short time and with low costs of labor and capital.

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