Application of Acoustic Emission Method for Control of Manual Arc Welding, Submerged Arc Welding

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Abstract. The experimental technique of the control the quality of welded joints in time of multi-pass welding and cooling of the weld seams based AE methods is the purpose of this paper.

Object of research are steel specimens, welded manual arc welding linear and circular seams. Control of the welding process is carried out using the acoustic emission method (AE).

Simulation of defects of the welding was performed at the expense of introduction in a welded seam of inserts from titanium, tungsten, slag. In the weld were created real defects: pores, hot and cold cracks, lack of fusion, penetration and slag inclusions. After welding, welds controlled visual measuring method by ultrasound, x-ray method and by metallographic techniques.

1. Introduction

At the present time traditional NDT methods such as radiographic (RK), ultrasonic (US), magnetic, that allow detecting of welding seams defects and defining of their conventional sizes, are largely used for estimation of welding seams quality.

Modern methods of welding seams quality control are presently becoming more and more popular. One of them is an acoustic emission method (AE), which allows detecting the internal welding seam defects during the welding process and cooling down and promptly correct them with the minimum volume of metal samples. The necessary load in this case is created by the means of thermal regime.

One of the main problems in welding seams examination during the welding process is the high activity of acoustic signals. The AE quality control method requires to distinguish the welding defect signals (cracks, patches with incomplete welding, pores, slag inclusions etc.) from the signals, produced by the welding arch, outflow of protective gas, melting, phase conversions, cracking of oxide film and other parasitic acoustic signals that follow welding and cooling down processes. In order to fulfill this task a methodical research for welding of straight butt seams was done.

The practical value of localization of AE defect signal in the real time mode is an ability to define the coordinates of the defect and to promptly correct them during the welding process with the minimum volume of metal samples without using traditional control methods. The complex use of AE method together with traditional methods of ND control allows increasing accuracy and quality of the control. The main advantage of the AE welding process control is in the ability to produce almost zero-defect welding seams.

2. Description of the technique

The method solutions for the given task are represented in works [1-3]. The most dangerous of the welding seam defects are the cracks. The work [3] for detection of AE signals from cracks against the noise background during a welding in a protective gas environment offers an approach, based on the nature of the waveform of the signals and spectral characteristics. As the two main attributes of crack registration it is offered to use the ratio of the average amplitude of the signal to the maximum value and the highest value of the spectral density of the signal, defined at the level 0.3 of the rated spectral density. For cracks the ratio is A_{av}/A_{max} >> A_{av}/A_{max} for noise. The top boundary of the spectral density is higher than 200 kHz. This approach is made more complex by the analysis of the spectral characteristics of the signals and requires using wide-band transformers. It is sometimes quite difficult to ensure such conditions during AE testing of industrial facilities.

Therefore in order to simplify the procedure of crack signal extraction it is preferable to use the set of traditional AE parameters. The preliminary analysis of the l waveforms is used in this case for defining of the traditional parameters, which form the space of attributes for differentiation of AE signals by characteristics (physical nature, dimensions etc.)

The target of the present research is to develop the elements of the method for detection of cracks in multi-pass welds in manual submerged arc welding.

3. Results

Metal steel 20 sheets with dimensions 600mm x 600mm with V-shaped groove (Fig.1) were welded on the territory of CKTI. The thickness of the welded sheets was in range from 17 mm to 27 mm. AE examination was done by AMSY-5 (Vallen Systeme). Sensors used VS150-RIC with the amplitude frequency response, represented on Fig.2. Welding defect control was done during the process of welding, crystallization and cooling down of the welding seam. On every passage the AE system located AE sources during the welding process.

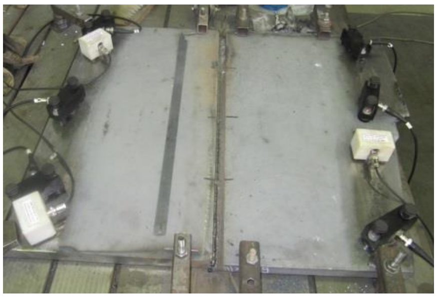


Fig.1. Location of the AE sensors on the sample of a butt welding junction

Welding defects were produced by specially chosen electrodes and welding modes, as well as naturally. Electrodes UONI-13/45 was used for production of pores. Electrodes T-590 was used for production of hot cracks. Electrodes ELZ NZ and a 20 hours time lag after welding were used for production of cold cracks.

Visual, ultrasonic and x-ray examination of the seam metal and adjacent area were done after the welding in order to detect the coordinates and sizes of the hidden defects.

After completion of the non-destructive testing the seam was cat and a metallographic study was done in order to confirm the presence of defects and define their formation.

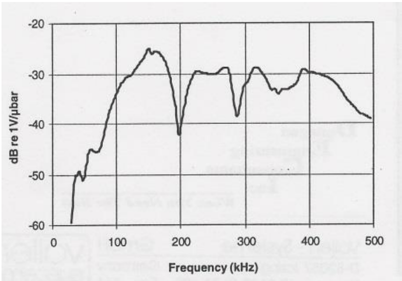


Fig.2. Sensitivity curve of a VS150-RIC sensor

3.1. Results of the visual and measurement control

The visual and measurement examination detected cracks, patches with incomplete welding and slag inclusions.

3.2. Results of the X-ray control.

The X-ray control detected hot and cold cracks, incomplete welding, pores and slag inclusions. Fig.3. presents the example of pores, incomplete welding and cracks.

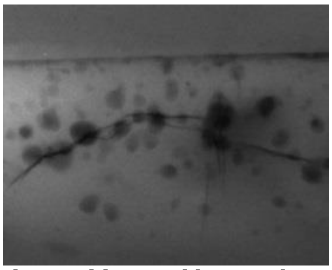


Fig.3. Pores, incomplete welding and hot cracks on the X-ray radiogram

3.3. Results of the US testing

The results of US testing for most damaged the weld section shown in Table 1.

Table 1. The results of US testing

X-Loc [cm]	The depth from the top surface [cm]	Amplitude relative to cut 3,5x2mm [dB]	The depth from the top surface [cm]	Amplitude relative to cut 3,5x2mm [dB]	The depth from the top surface [cm]	Amplitude relative to cut 3,5x2mm [dB]
46	8	+6	11	+5		
47	8	+8				
48	8	+10	22	-2		
49	8-11	+2	23	+2		
50	8	+7	25	+2		
51	11	+12	23	+6		
52	25	+11				
53	11	+5	12	+0	26	+4
54	8	+5	25	+3		
55	9	0	25	+3		
56	14	0	24	+3		
57						
58						
59						

Data from the US testing was recalculated through the size of the cut and amplitude of defect signal exceeding the cut signal. These data was summed up for each centimeter of the seam and the results are represented on Fig.4 as distribution of the total defect area over the length of the welding seam.

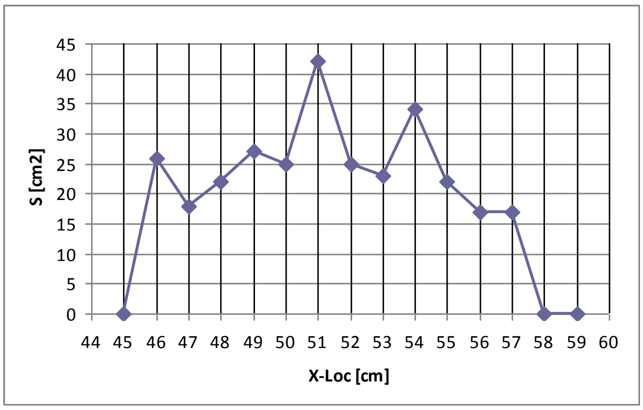


Fig.4. Distribution of the total defect area over the length of the welding seam

3.4. Results of the metallographic testing

Metallographic testing was done in order to estimate the presence, sizes and character of the defects in the control welding samples. In order to examine the nature and sizes of the internal defects the samples were cut transversally into thin sections, which were further brushed and polished.

The visual and measurement control revealed the following impermissible defects:

- The longest cracks were up to 0,9 mm deep. Cracks up to 0,5 mm deep go from a spot of incomplete welding in the root of penetration. The spot of incomplete welding in the root of penetration was up to 1,5 - 4 mm deep.

- Multiple pores in the melted metal, mostly in the upper bead. The biggest pore was 2,0×4,0 mm in size.

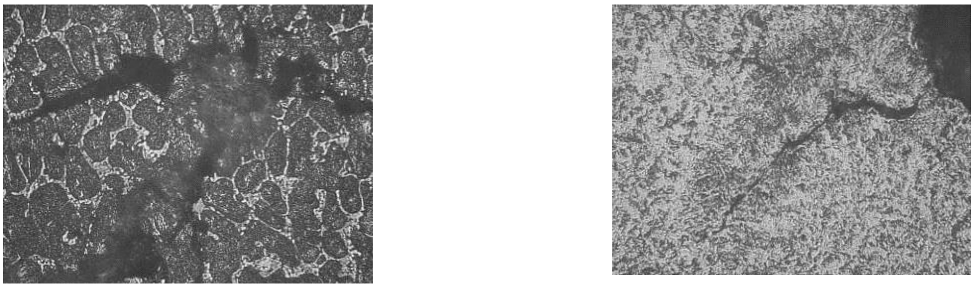
The character of the revealed defects was examined with an optic microscope at magnification of 100 and 500. The general view of the crack and pore defects are shown on Fig.5.

Fig.5. The general view of the defects: incomplete welding, crack and pore

The detected cracks in the build-up metal are classified mostly as hot, developed during welding. The cracks typically have wide cavities, filled with oxides. Certain cracks are focused and can be classified as cold, developed after the welding.

3.5. AE testing results

Fig.7 shows distribution of AE sources by the length of the seam (vertical axis) and by time (horizontal axis) for one of the typical welding stages. Only the events with an amplitude higher than 60dB are shown, high-amplitude (Amp>90 dB) events are marked additionally.



(a) (b)

Fig.6. Cracks in build-up metal: (a) – hot cracks, (b) – cold cracks.

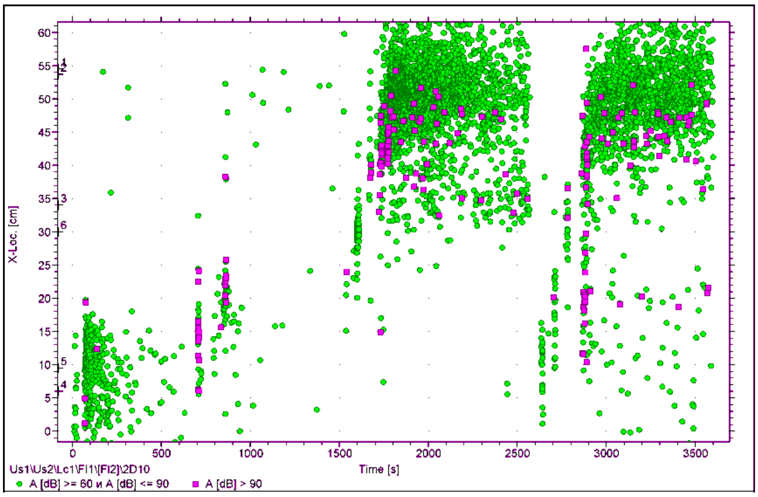


Fig.7. Distribution of AE sources by the length of the seam and by time during the welding process

It is obvious, that coordinates of the AE events from the noise sources and from the probable defects is related to moving of the electrode during the welding process. However extraction of useful signal from the common data for this diagram is not possible without additional filtration.

Three space-time sites with the known properties were studied in order to reveal peculiarities in the AE signals and define the parameters of filtration:

(1) X = 25-30 cm – a site of welding seam without defects. This patch should have only the signals from the welding process, development of pores, phase conversions in the metal and cracking of slag coverage.

(2) Space-Time site: X = 16-26, Time=849-865 s, with removal and blow-down of the slag coverage.

(3) X = 45–50 cm – a site of welding seam with hot and cold cracks.

Each site (process) has diagrams of distribution of some basic AE characteristics. Figures 8-10 show distribution of the AE events (by the first hit in event) by Counts (a), by Energy (b), by Amplitude (c) and by Rise-Time (d) for sites (1) (Fig.8), (2) (Fig.9) and (3) (Fig.10).

Fig.11 shows initial fragments of waveform and their spectrum analysis for the first hits of three different AE events on channel 5. The event on picture 11a (insignificant structural change) can be regarded as typical for site (1), the event on picture 11b (noise from blow-down) is typical for site (2), the event on picture 11c (big crack) is typical for site (3).

Based on the spectral analysis correlation Gauss function was applied for each hit has in order to estimate the input of several dominating frequencies.

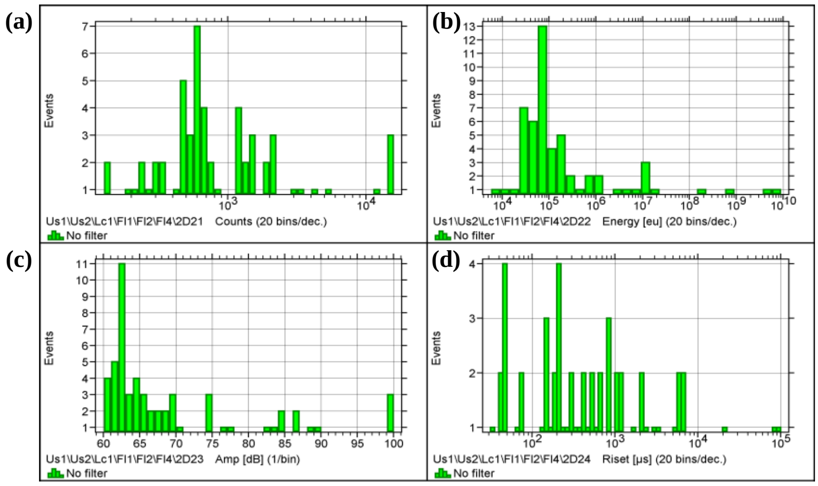


Fig.8. Distribution of AE events (first hit) by Counts (8a), by Energy (8b), by Amplitude (8c) and by Rise-Time (8d) for section (1) (X = 25-30 cm).

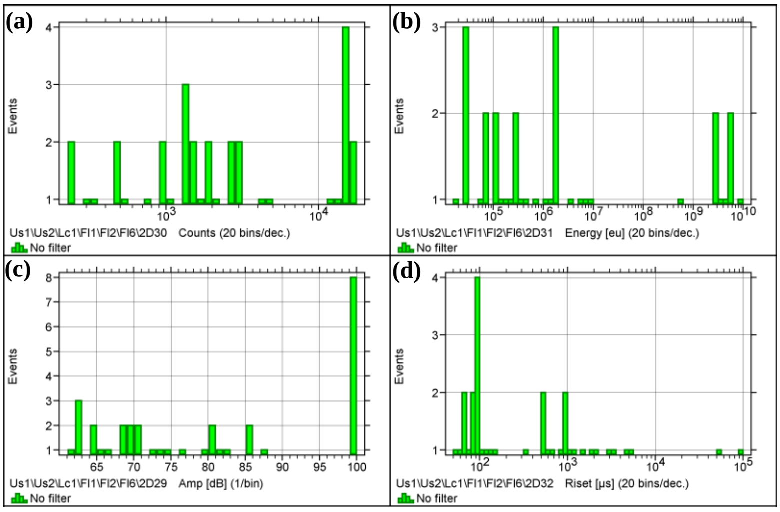


Fig.9. Distribution of AE events (first hit) by Counts (9a), by Energy (9b), by Amplitude (9c) and by Rise-Time (9d) for space-time interval (2) (X = 16-26, Time = 849-865 s).

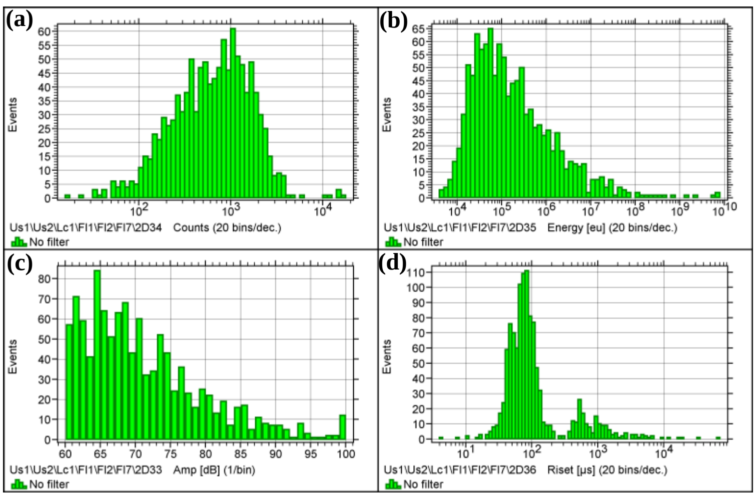


Fig.10. Distribution of AE events (first hit) by Counts (10a), by Energy (10b), by Amplitude (10c) and by Rise-Time (10d) for section (3) (X = 45-50 cm).

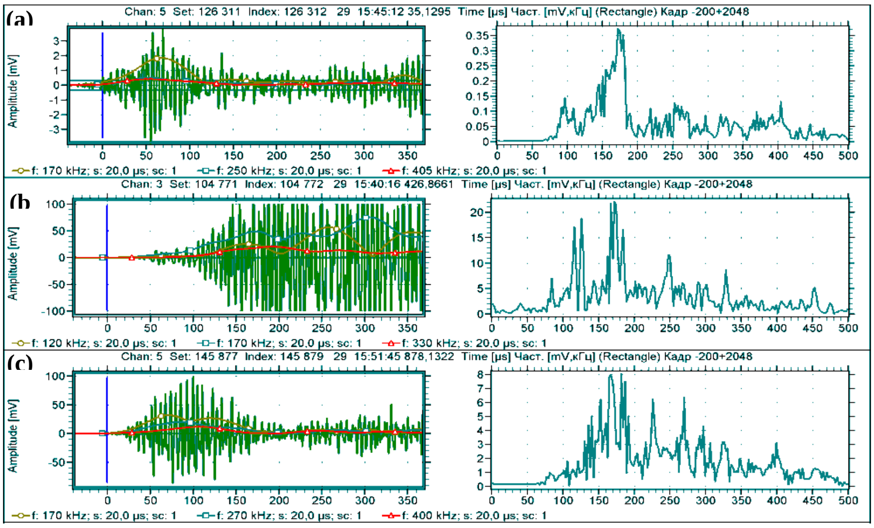


Fig.11. Examples of waveform and their spectrum analysis of first hits AE events different type:

(a) Insignificant defect; (b) Blow down; (c) Big defect.

4. Analysis of AE testing results

According to the data analysis results it is proposed to use a combination of the following hits characteristics as diagnostic parameters: Energy, number of oscillations (Counts), time of hit rising (Rise Time). These characteristics form a two-dimensional space of feature ($E*10^{-3}$/ Counts vs. RT), in which AE events of different type are separated tolerably (Fig.12).

Indeed, the high values of quantity E^/C (E^= $E*10^{-3}$), that can be called as “the hit energy density”, are typical for a noise signal (Fig.11b). The result of application of the Gauss correlation for hits from two structural sources (i.e. for AE events of surpassingly one nature but different scale, Fig.11a, 11c) reveals that they are considerably different in the high-frequency zone. Apparently it is related to the earlier attenuation (“falling under the threshold”) of the high-frequency component of the low energy process signal. But in any case, the ratio E^/C for it decreases not only due to the low amplitude, but also as a result of a loss of the high-frequency energy.

High values of Rise Time parameter are typical for many types of noise. Therefore it is convenient to use it as the second variable in the space of attributes, separating useful signals from noise signals.

Numeric values for the boundaries of the zone of useful signals on Fig.12 are defined from correlation of AE data with characteristics of defects, made during the welding.

In the distribution on Fig.12 the hits, fell into the red rectangular satisfy the criteria values and comply with the signals from big cracks in the seam metal. The hits in the upper and the right part of the distribution as a rule relate to different kinds of noise.

Finding the numerical value of the bottom boundary of E^/C requires a separate discussion. It should be defined depending on the minimum size of the defect, which should be detected by testing. The other reason for limiting the value of E^/C from the bottom might be the rate of sensitivity of the traditional NDT methods if they are used for examination of AE results. It is known, that the rate of sensitivity of the AE method is higher than of the majority of such methods. If it is needed to detect the defects undetectable for the traditional methods, the boundary could be lowered to the necessary level.

The use of the proposed criteria as a filter is shown on Fig.13. These are the results of processing the data, shown on Fig.7. The red marker highlights the location AE events (Lucy ≤ 2 cm), identified as cracks of considerable sizes. It can be seen, that it is possible to locate the potential defect against the high level of noise.

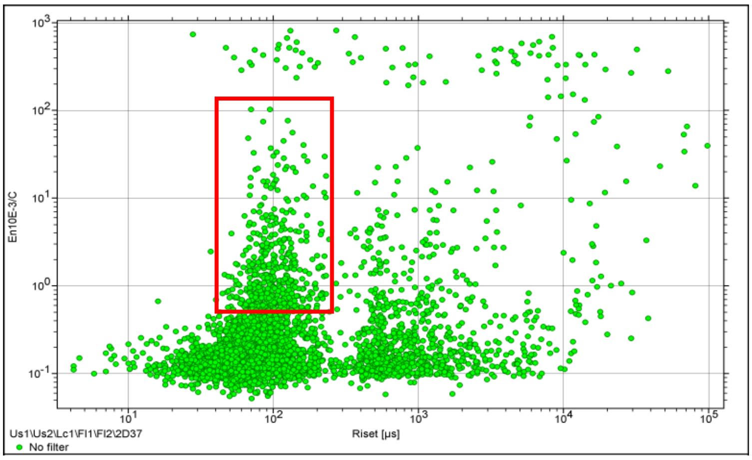


Fig.12. Space of feature for extraction of AE events, related to formation of big cracks during the welding

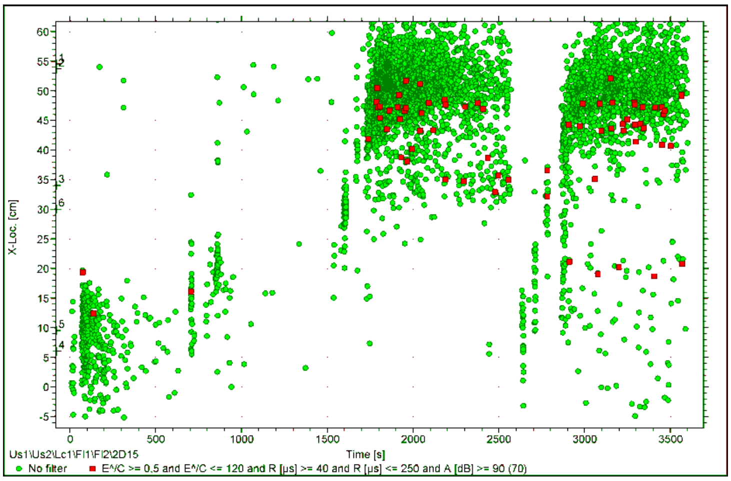


Fig.13. The result of using the filter for detecting cracks during welding

For the site X = [45;60] cm, containing according to the used criteria the maximum number of defects, we have drawn up a distribution of the sum of amplitudes of the filtered signals by coordinates of the correspondent AE sources and compared this distribution with the distribution of the total area of the defects along the length of the welding seam (Fig.4). The result is shown on Fig.14.

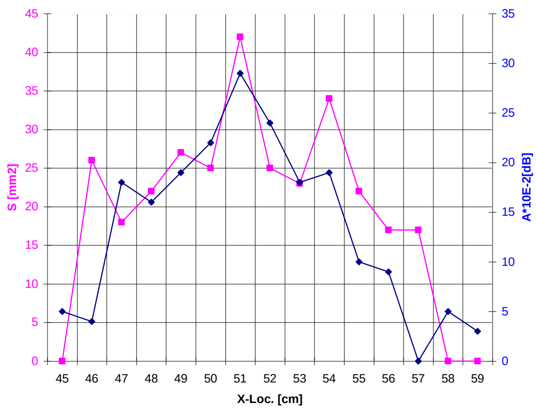


Fig.14. The dependence between the Sum defects area and Sum of Amplitudes of first hits AE events filtered by “E^/C vs. RT” parameter in the welding seam section X = [45;60] cm.

The diagram on Fig.14 shows a good correlation of the results of AE and results of ultrasonic testing.

5. Conclusions

1. Experimental tests of process of welding 20 steel sheets with the use of capabilities of Vallen Systeme were done in order to optimize the AE quality control method for multi-pass welding seams in manual submerged arc welding.

2. The real defects (pores, hot and cold cracks,) were produced by a special welding technology. Visual and measurement, ultrasonic and X-ray testing of the welding results were done. Metallographic analysis of the detected defects was done additionally.

3. The results of the AE testing showed a good compliance with results of the ultrasonic testing. The research showed, that the proposed criteria (E^/C vs. RT) has a good potential for detection of cracks, formation during the welding process.

References

[1] V.I. Ivanov, V.M. Belov, Acoustic-emission testing of welding and welded joints. M: machine-building, 1981, 184 p.

[2] V.I. Ivanov, IE Belov. The method of acoustic emission. Reference . Ed. by V.V. Klyuev , v. 7, M: machine-building, 2005, 825 p.

[3] Patent FGUP "Krylov Shipbuilding Recearch Institute " RU 2156456 "Method of detection during welding defects in the welds and determine their location by acoustic emission signals"