Analysis of Errors in Location of Flaws in Multipass Welds Using Different Clustering Methods

L. N. Stepanova, S. I. Kabanov, I. S. Ramazanov, and K. V. Kanifadin

Abstract—Titanium and duralumin inserts were introduced into a weld to imitate welding flaws in St3 steel samples. Analysis of the accuracy of locating the introduced flaws with different clustering methods (by digitized shape, main informative parameters, the rise rate of leading-edge envelope) has shown that these methods involve considerable time expenditures. The developed dynamic clustering has been combined with the clustering by main informative parameters and allowed in situ location of flaws during welding, while the weld has not been completed yet.

Keywords: welding, insert, flaw, acoustic emission, error, cluster, dynamic clustering

INTRODUCTION

The main reason for reducing the technological strength of welded joints is the presence of flaws (cracks, incomplete fusions, slag inclusions, etc.) that form during welding and are revealed by different nondestructive testing (NDT) techniques. The flaws promote in-service nucleation and development of cracks [1, 2].

Such traditional NDT methods as ultrasonic and radiographic control are used in multipass welding and allow one to evaluate chilled welded joints. Acoustic emission (AE) has recently been used. It allows one to reveal internal defects during the welding and cooling of a joint, thereby allowing runtime rework and minimizing the volumes of cutout metal. In this case, the required loading of the test object is created due to the thermal mode.

Welding is accompanied by a large number of parasitic signals that are also registered by the AE system. Since acoustic emission has low noise immunity, cluster analysis techniques are widely used in order to eliminate this drawback. These techniques allow one to group signals from different sources and exclude parasitic signals. The greater the number of AE-signal parameters that are compared in clustering, the more accurately the signals are separated by origin. However, this reduces the performance of the diagnostic system.

Clustering is a common technique for processing AE information [3], but its capabilities in online testing of welding processes need to be improved.

Gomera et al. [1] showed that signals from flaws of considerable sizes form compact clusters in a two-parameter space of signs, the first parameter calculated from the signal duration, energy, and number of oscillations and the second one determined by the signal rise time. Additional information on the process of welding and cooling can be obtained by amplitude-frequency analysis [3—5].

A flaw in a weld can be recognized by the maxima in the distribution of the total amplitude of localized AE signals. This increases the significance of precise location [2, 4]. However, it is impossible to allow for all parameters of AE signals simultaneously with these approaches to clustering; this may deteriorate the reliability of flaw detection. In multipass welding, it is important to receive information about flaws online, immediately after they appear on the location image. Therefore, one needs such a method of processing AE information that allows one to analyze the totality of AE signal parameters in the online mode.
in order to gather information on the signal sources. Dynamic clustering of AE signals from a set of their parameters is one of such techniques [2].

Reducing the number of compared parameters improves the performance of information processing while impairing the accuracy of location. Therefore, when choosing the clustering method one needs to consider balancing information-processing performance and attainable accuracy of location.

The aim of this work is comparative analysis of various AE-signal clustering techniques that are used when determining the errors of flaw detection in multipass welding.

RESEARCH PROCEDURE

Steel St3 200 × 500 × 8 mm samples were multipass welded in the research. Four acoustic-emission transducers (AET) were mounted on each sample. EA-981/15 welding rods 4 mm in diameter were used. Titanium and duralumin inserts were introduced into the weld to imitate flaws in the samples. The titanium insert was at a distance of 130 mm from the weld edge on the side of AET0-AET1 transducers. The duralumin insert was at a distance of 360 mm. AE signals were registered using an STsAD-16.10 system (certificate no. RU.C.27.007.A no. 40707) with “floating” selection threshold. Wideband PK 01-07 transducers with a passband of 100–700 kHz were used as AETs. Signal recording and source location were performed online during welding and cooling of a welded joint.

In total, 2492 AE signals were localized from the results of testing. Three methods of clustering were used to process the information gathered, viz., by digitized shape, by main informative parameters (amplitude, the rise time of the leading edge of AE signal envelope, predominant frequency, the number of oscillations), and by the rise rate of the leading-edge envelope. These methods of clustering can be used both in the mode of post-processing AE signals and combined with the method of dynamic clustering [2].

In digitized-shape clustering, the maximum of the correlation function

\[
R_{i,k} = \max_{a} \frac{\sum_{l=1}^{N} U^{l}_{m} U^{l+a}_{k}}{\sqrt{\sum_{l=1}^{N} (U^{l}_{m})^2 \sum_{l=1}^{N} (U^{l+a}_{k})^2}},
\]

was determined, where \(R_{i,k}\) is the “current signal—cluster reference signal” correlation coefficient; \(U^{l}_{k}\) is the count with index \(l\) of the current AE signal with number \(k\); \(U^{l}_{m}\) is the count with index \(l\) of the AE reference signal; \(N\) is the number of counts in the correlation computation “window”; and \(a\) is the shift within which it is calculated.

If the value of the correlation function \(R_{i,k}\) in Eq. (1) exceeds the preset threshold level, both signals are ascribed to one cluster. Figure 1a shows a cluster at the location of the titanium insert. Clustering by digitized shape produced 160 clusters with 1758 located AE signals. The remaining signals were ascribed to the zeroth cluster. The clusters were mainly placed near the inserts. The procedure of clustering and determining the coordinates of AE signals was taking approximately 3–5 min, a period that is admissible when evaluating welded joints during their cooling.

Location of flaws in multipass welding requires that the testing time be shortened. Clustering by a set of informative parameters of AE signals was applied to achieve this. At the first stage of clustering, the location error was determined for the reference AE signal and a function of distance between the reference and other signals was calculated [2]. Signals with the value of the function less than the location error were allowed to pass through the second stage of clustering. At the second stage, the informative parameters of the reference signal and the signals that had passed the first stage were compared. If these parameters fell into one interval, the signals were merged into one cluster.

Figure 1b presents a cluster that was obtained in clustering by parameters; it is located where the duralumin insert was introduced. The registered signals were placed into 61 clusters near the inserts. The zeroth cluster contained 1627 AE signals. The procedure of clustering by parameters took 30–40 s. This clustering method is thus suitable for evaluation of flaws in the process of multipass welding.

When using clustering by the rise rate of the leading-edge envelope, three threshold levels were set that divided the leading edge of an AE pulse into two parts [2]. Further clustering was performed by the rise rate of the leading edge on each of the two parts. If the number of signals that had fallen into one cluster was above a preset critical value, a conclusion was drawn about this source emitting AE signals. Figure 2 shows