Designation: E3052 – 21

Standard Practice for Examination of Carbon Steel Welds Using An Eddy Current Array[1]

This standard is issued under the fixed designation E3052; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers the use of an eddy current array (ECA) or an eddy current sensor for nondestructive examination of carbon steel welds. It includes the detection and sizing of surface-breaking cracks in such joints, accommodating for nonmagnetic and nonconductive coating up to 5 mm thick between the sensor and the joint. The practice covers a variety of cracking defects, such as fatigue cracks and other types of planar discontinuities, at various locations in the weld (heat-affected zone, toe area, and weld cap, for example). It covers the length and depth sizing of such surface-breaking discontinuities. This practice can be used for flush-ground and not flush-ground welds. For specific ferrous alloys or specific welded parts, the user may need a more specific procedure.

1.2 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

E2884 Guide for Eddy Current Testing of Electrically Conducting Materials Using Conformable Sensor Arrays

E2905 Practice for Examination of Mill and Kiln Girth Gear Teeth—Electromagnetic Methods

2.2 *ASNT Documents*[3]

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification In Nondestructive Testing

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *ISO Standard:*[4]

ISO 9712 Nondestructive Testing—Qualification and Certification of Nondestructive Testing Personnel

2.4 *AIA Standard:*[5]

NAS–410 Certification and Qualification of Nondestructive Testing Personnel

3. Terminology

3.1 *Definitions:* For definitions of terms relating to this practice, refer to Terminology E1316, Guide E2884, and Practice E2905. The following definitions are specific to the examination of carbon steel welds using an eddy current array:

3.1.1 *air reference measurement, n*—the measured response of the sensor and instrumentation to a nonmagnetic and electrically insulating reference material such as air.

3.1.1.1 *Discussion*—This measurement is typically used as part of the standardization process and to verify operation of the instrument. Measurements on conductive materials after standardization with an air reference measurement should provide absolute electrical properties, such as electrical conductivity, and lift-off values.

3.1.2 *encoder, n*—a spatial sensing device (based on mechanical, optical, or electromagnetic principles, for example) that allows for accurate monitoring of a sensor's

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic Method.

Current edition approved Nov. 1, 2021. Published November 2021. Originally approved in 2016. Last previous edition approved in 2016 as E3052 – 16. DOI: 10.1520/E3052-21.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[5] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, http://www.aia-aerospace.org.

***A Summary of Changes section appears at the end of this standard**

position during data collection and is typically used to construct spatially referenced data presentations.

3.1.3 *examined part reference measurement, n*—the measured response of the sensor and instrumentation to a region of the part to be examined for which no discontinuities are present.

3.1.3.1 *Discussion*—This measurement is typically used to compensate for differences in material properties between the examined material and a reference material used to develop a correlation between the eddy current sensor reponse and a characteristic of a discontinuity, such as a crack depth.

3.1.4 *known material reference measurement, n*—the measured response of the sensor and instrumentation to a given material with known, homogeneous electrical conductivity and magnetic permeability (such as aluminum 6061-T6, for example) for which no discontinuities are present.

3.1.4.1 *Discussion*—This measurement is typically used as part of the standardization process and to verify operation of the instrument.

4. Significance and Use

4.1 *Eddy Current Arrays for Crack Detection and Sizing in Carbon Steel Welds*—Eddy current sensor arrays permit rapid examination of carbon steel welds for surface-breaking cracks located on the surface closest to the sensor array. As described in Guide E2884, these sensor arrays can have multiple drive-sense pairs for each element of the array or a large single drive winding construct with multiple individual sense elements. However, not all ECA probe designs allow for accurate depth sizing of such discontinuities over a significant range (several millimeters, for example). To achieve proper crack depth sizing, the system shall exhibit certain characteristics, such as: *(1)* a lift-off signal that allows monitoring the lift-off over the range of values of interest for the examination, *(2)* suitable separation between the lift-off signal and the defect signal (this depends upon the instrument used and can be viewed as a phase separation in an impedance plane display), *(3)* the capability to make use of the lift-off values for crack depth determination, *(4)* the capability to take into account material properties variations for crack depth determination along and across the weld, and *(5)* a uniform sensitivity for the sensing elements of the array in order to provide an effective single-pass examination, which is expected when using an array sensor.

4.2 *Array Sensors and Single Sensing Element Sensors*—Depending on the weld geometry, it may be possible to use either a sensor array or a sensor with a single sensing element. The sensor array generally provides a better spatial representation of the weld properties and an improved probability of detection for discontinuities. The size of the array, as well as the size and number of individual sensing elements within the array depend on the weld geometry and other factors such as target discontinuities. When a single-sensing element sensor is used, it shall produce signals that exhibit the characteristics listed in 4.1 and the maximum distance from the scan line to a target discontinuity, potentially detectable at a specified probability of detection, is typically 5 mm. Imaging of the weld region can be obtained with a single element sensor if raster scanning is performed.

4.3 *Conformable Sensors*—Examining welds that are not ground flush typically requires a conformable array sensor, minimally along one axis. A conformable sensor is key to allowing the individual sensing elements to follow the profile of the weld cap, and to provide a uniform response over the region of interest during the examination when the array is oriented transverse to the weld and scanned along the length of the weld.

4.4 *Crack Depth Range*—The crack depth sizing range over which the array sensor can provide accurate measurement depends on the sensor geometry, such as individual sensing element size and configuration. For example, larger sensing elements may provide the ability to size deeper cracks, but offer limited detection capability for shallow cracks. Appropriate array sensor selection and operating frequency is critical to ensure adequate performance for a given application. Typical operating frequencies range between 10 kHz and 500 kHz.

4.5 *Coating Thickness Range*—The coating thickness range over which the array sensor can reliably detect and size cracks depends on the individual sensing element size and overall probe geometry, among other parameters. For any coated weld examination, a verification that the coating thickness is within the probe specification range is critical to ensure adequate results.

4.6 *Crack Length Range*—The crack length range over which the array sensor performs best depends on the individual sensing element size and on any data processing performed on the data. The size of the individual sensing element mainly affects the minimum crack length detectable, while data processing (a high pass filter, for example) may have a critical impact on the maximum measurable crack length.

4.7 *Sensitivity Uniformity*—In order to provide a high probability of detection and allow accurate length and depth sizing, it is critical that the sensitivity across the sense elements of the array be uniform. The array sensor shall exhibit variations in sensitivity no greater than 15 %. The sensitivity across the array depends on the size and configuration of single sensing elements and shall be considered to determine the overall array accuracy. Overlapping individual sensing elements may be required to achieve the adequate level of sensitivity uniformity (for example, this can be achieved with multiple staggered rows of single sensing elements or with a linear array oriented at a non-perpendicular angle to the scan direction).

4.8 *Sizing and Accuracy*—Depending on the material properties and weld surface condition, there is an optimal measurement performance range for the system. The instrument and sensor array probe, the air reference measurement and known material reference measurement, along with the operation procedure typically allow depth sizing within ±30 % of its true depth. Depth sizing accuracy is reduced when the system is operated outside its optimal range.

5. Interferences

5.1 *Material Properties:*

5.1.1 *Base Metal*—Magnetic permeability and electrical conductivity of the metal can affect the eddy current measurements, and as such, may have an impact on the crack sizing accuracy. The system must be able to compensate for variations in the magnetic permeability and electrical conductivity typically found in carbon steels. For example, a standardization technique can be use to measure and adjust the sense element responses to reduce the sensor response variations to the base metal property variations.

5.1.2 *Variations Across the Weld*—In welded structures, the magnetic permeability and electrical conductivity may vary between the weld metal, the heat affected zone, and the base metal. Considering the array sensor is moved along the weld axis, each individual sensing element is usually exposed to relatively constant material properties. However, from one individual sense element to another within the array, significant properties variation may exist and the inspection system shall be able to compensate for those local variations in order to avoid noise and undesired signals in the C-scans.

5.2 *Weld Geometric Features*—Geometric features in the weld such as bumps and craters can create non-relevant localized signals that will contribute to increasing the noise level perceived by each sensor. Typically, such geometric features produce signals that exhibit a phase response that is significantly different from a crack-like discontinuity, and can be easily discriminated. However, the presence of several, large geometric features may reduce the overall sensitivity of the probe.

5.3 *Coating*—The presence of a nonconductive and nonmagnetic coating over the weld can affect the depth sizing accuracy. If a coating thickness exceeds the specified coating thickness range of the system, the crack depth sizing accuracy can be significantly reduced.

5.4 *Curvature of Examination Surface*—The examination of welds located along a curved surface may affect lift-off and coating thickness evaluation if the individual sense elements are not properly in contact with the surface (normal to the surface). In general, the radius of curvature of the inspected part should be large compared to the sensor length. Bi-dimensional conformable arrays may have to be used to ensure appropriate sensor contact with the surface.

5.5 *Surface Roughness*—Surface roughness will create localized lift-off variations that are likely to be different from one sensing element to another within the array. To yield accurate depth sizing, the individual lift-off variations must be monitored and these values used when compensating crack depth measurements.

5.6 *Residual Magnetism in Base Metal*—Local residual magnetism may produce noise signals that can affect data interpretation. Demagnetization of the surface is recommended if the examination is performed after a magnetization technique, such as magnetic particle, to ensure that the surface is in the non-magnetized state.

5.7 *Temperature*—Eddy current measurements are generally affected by the temperature of the material under examination. Depth sizing may be affected by electrical conductivity variations associated with temperature variations. Temperature correction is required when the examination has to be done outside the normal operation temperature of the sensor array.

5.8 *Pressure of the Probe Against Surface Under Examination*—Readings can be affected by the pressure exerted on the conformable array probe when pressed against the surface being examined. The pressure should be sufficient to maintain each individual sense element in contact with the part being examined. Array sensors made of a rigid body matching the profile of the surface under examination only require minimal pressure to maintain good contact with the surface but still need to ensure that the lift-off is consistent between each sense element and throughout the examination.

6. Basis of Application

6.1 The following item is subject to contractual agreement between the parties using or referencing this standard practice.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as specified in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with the requirements specified in the contractual agreement.

6.6 *Timing of Examination*—The timing of examination shall be in accordance with the applicable contractual agreement.

6.7 *Extent of Examination*—The extent of examination shall be in accordance with the applicable contractual agreement.

6.8 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 9 unless otherwise specified. Since acceptance criteria are not specified in this practice, they shall be specified in the contractual agreement.

7. Calibration and Standardization

7.1 The sensor shall be connected to the instrument. Once turned on, the system should be allowed sufficient time to stabilize in accordance with the manufacturer's instructions before use.

7.2 The instrument shall be standardized in accordance with manufacturer's instructions. The instrument standardization includes the measurement of an air reference point and, if needed by the instrument, a known material reference point to compensate for differences between sense elements within the array. In addition, if needed by the instrument, the measurement of an examined part reference point may be required to compensate for material property differences between the examined material and the typical carbon grade steel material used for creating the correlation between the sense element response and crack size.

7.2.1 *Air Standardization*—Air standardization is performed by taking an air reference measurement for each individual sense element and adjusting the sense element responses based upon these measurements. Measurements on conductive materials after an air reference measurement should provide absolute electrical properties and lift-off values.

7.2.2 *Known Material Reference Standardization*—The known material reference standardization uses a known material reference measurement for each individual sense element. The values from this measurement are used with air reference measurement values to adjust the gain and phase of each sensing element. This action standardizes the overall probe response and ensures uniform sensitivity within the array.

7.2.3 *Examined Part Reference Measurement*—The examined part reference measurement involves the measurement of the sensor array response on the material to be examined over a region of the material that does not contain discontinuities. This response is compared with the expected response from a typical carbon steel grade material, which is incorporated in the system. This measurement allows compensation for the difference in material properties (for example, magnetic permeability and electrical conductivity) between the examined material and the typical carbon grade steel material to maintain sizing accuracy.

7.3 Standardization should be repeated at intervals established based on experience for a given application, including performance verification (see 7.5). Partial standardization, where only the examined part reference measurement is performed, must be done every time the material of the component under examination is changed.

7.4 *System Performance Verification*—System performance verification refers to measurements of the air and known material reference to confirm that the measured responses are within specified tolerances for the application. This serves to validate the standardization and verify proper instrument operation.

7.5 *Discontinuity System Performance Verification*—Reference parts with a known discontinuity are not required for standardization of array probes that use a compensation technique or a model to characterize the sensor response, since standardization can be successfully performed on a known material reference. However, discontinuity performance verification may be required, particularly when the material properties of the part under examination are outside the compensation range allowed by the system or when the models do not accurately represent the part being examined. In such cases, discontinuity performance verification should also be made with different coating thickness by using insulating shims to vary lift-off by a known amount and verify that the measured lift-off change and discontinuity depth corresponds to the expected values.

7.6 Instrument calibration should be performed in accordance with manufacturer's instructions or when a malfunction is suspected.

8. Procedure

8.1 Operate the instrument and software in accordance with the manufacturer's instructions, giving appropriate attention to factors listed in Section 5.

8.2 The sensor shall be connected to the instrument. Once turned on, the system should be allowed sufficient time to stabilize in accordance with the manufacturer's instructions before use.

8.3 Perform system standardization by measuring the air reference, the known material reference, and the examined part reference as specified in Section 7. Data collected during the standardization should be recorded and archived with the inspection data.

8.4 In general, the sensor array should be placed over the weld, the encoder value set adequately, and data collected by the system while scanning at a typical speed not exceeding 200 mm/sec. In the case where a single sensing element is used, there is typically no encoder involved and multiple scans may be required to effectively cover the region of interest.

8.5 After scanning, the data file is analyzed. All C-scans (for array sensors) and strip charts (for single sensing elements) should be carefully analyzed to locate any indication that exceeds the local noise level (typically by ≥6 dB). Indications shall be classified by the analyst as either non-relevant or flaw indications.

8.5.1 Non-relevant indications may be produced by incomplete probe contact with the surface, probe wobble, geometric features, or changes in the material properties on the surface being examined, for example.

8.5.2 Flaw indications are produced by flaws on the surface examined, which cannot be considered as non-relevant indications. Typically, indications that exhibit a phase response equivalent to a defect phase response shall be evaluated and reported as flaw indications. The instrument should be able to provide an estimate of the flaw depth and length. The depth estimation can be done by using the vertical amplitude of the signal response, or any other parameters that correlate with the flaw depth. The lift-off measured by the sensor, using, for example, the horizontal amplitude of the signal response, should be used to refine the crack depth estimate. Flaw length estimation can be done with the same sensor or an alternate sensor sensitive to the tips of the flaw. An encoder should be used to accurately measure the length.

8.6 Observe the following precautions:

8.6.1 *Dead Zone*—Given the physical size of the probe assembly, it is typical for a sensor array to have a dead zone at the very beginning of a scan, especially for sensor arrays