Standard Practice for Electromagnetic (Eddy Current) Sorting of Nonferrous Metals[1]

This standard is issued under the fixed designation E703; 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 describes a procedure for sorting nonferrous metals using the electromagnetic (eddy current) method. The procedure is intended for use with instruments using absolute or comparator-type coils for distinguishing variations in mass, shape, conductivity, and other variables such as alloy, heat treatment, or hardness that may be closely correlated with the electrical properties of the material. Selection of samples to evaluate sorting feasibility and to establish standards is also described.

1.2 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E105 Practice for Probability Sampling of Materials

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

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 *AIA Standard:*[4]

NAS-410 Qualification and Certification of Nondestructive Testing Personnel

3. Terminology

3.1 Standard terminology relating to electromagnetic examination may be found in Terminology E1316, Section C: Electromagnetic Testing.

4. Summary of Practice

4.1 The techniques that are primarily used in electromagnetic sorting employ the absolute (single-) and comparative (two-) coil methods using either encircling or probe coils. The decision of whether to use single-coil or two-coil operation is usually based on empirical data. In the absolute-coil method (encircling or probe), the equipment is standardized by placing standards of known properties in the test coil. The value of the examined electrical parameter, which may be correlated with alloy, heat treatment temper, or hardness, is read on the display of an indicator. In the comparative coil method (encircling or probe coils), the test specimen in one coil is compared with a reference standard in a second coil to determine whether the test specimen is within or outside of the required limits.

4.1.1 *Absolute Coil Method:*

4.1.1.1 *Encircling Coil*—Various reference standards are inserted consecutively in the test coil, and the controls of the instrument are adjusted to obtain an appropriate response. Typically, three samples would be used representing the upper, lower, and mid-range for which standardization is required. The examination is then conducted by inserting the specimens to be sorted into the test coil, and observing the instrument response.

4.1.1.2 *Probe Coil*—The probe coil is placed consecutively on the reference standards and the controls of the instrument are adjusted for appropriate response (see 4.1.1.1). The examination is then conducted by placing the probe on the specimens to be sorted and observing the instrument response.

4.1.2 *Comparative Coil Method:*

[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.

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[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 Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

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

4.1.2.1 *Encircling Coil*—Reference standards representing the minimum or maximum limits, or both, of acceptance or sorting category are inserted in the reference and test coil. The instrument controls are adjusted for appropriate responses. The examination is then conducted by inserting specimens to be sorted in the test coil, leaving the known reference in the reference coil and observing the instrument response.

4.1.2.2 *Probe Coil*—Both probe coils are placed on the reference standard representing the minimum or maximum limits, or both, of acceptance or sorting category. The instrument controls are adjusted for appropriate responses. The examination is then conducted by placing the test probe on the specimens to be sorted (the other probe is left on the reference standard) and observing the instrument response.

4.2 The range of instrument response must be so adjusted in the initial step that the anticipated deviations will be within the range of readout.

4.3 Both absolute and comparative methods using encircling coil(s) require comparing the specimens to be examined with the reference standards. Two or more samples representing the limits of acceptance may be required. In the absolute method, the electrical reference signal from the instrument is adjusted with the reference standard in the coil. In the comparative method, any electromagnetic condition, that is not common to the test specimen and the reference standard, will produce an imbalance in the system. The comparative method is usually more stable since it suppresses most of the interferences.

4.4 The examination process may consist of manual insertion of one specimen after another into the test coil or an automated feeding and classifying mechanism may be employed. In automated setups, it is sometimes necessary to establish empirically the time required for the test specimen to remain in the test coil while the reading is being taken, especially if low frequencies are employed.

5. Significance and Use

5.1 Absolute and comparative methods provide a measure for sorting large quantities of nonferrous parts or stock with regard to composition or condition, or both.

5.2 The comparative or two-coil method is used when high-sensitivity examination is required. The advantage of this method is that it almost completely suppresses interferences.

5.3 The ability to accomplish these types of separations satisfactorily is dependent upon the relation of the electric characteristics of the nonferrous parts to their physical condition.

5.4 These methods may be used for high-speed sorting in a fully automated setup where the speed of examination may approach many specimens per second depending on their size and shape.

5.5 Successful sorting of nonferrous material depends mainly on the variables present in the sample and the proper selection of frequency and fill factor.

5.6 The accuracy of a sort will be affected greatly by the coupling between the test coil field and the examined part during the measuring period.

6. Basis of Application

6.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally recognized nondestructive testing (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.

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

6.3 *Acceptance Criteria*—Since acceptance criteria are not specified in this practice, they shall be specified in the contractual agreement.

7. Interferences

7.1 The influence of the following variables must be considered for proper interpretation of the results:

7.1.1 The correlation shall be established so that electrical properties of various groups do not overlap and are well defined in the standardization procedure used.

7.1.2 The examination frequency must be selected to provide a well-defined separation of variables.

7.1.3 The temperature of the reference standard and test specimen shall be controlled within limits that will permit a well-defined range of conductivity or permeability, or both, for which the correlation of the group or groups is valid. Cooling of the reference standard when high field strengths are used or allowing test specimens to cool or heat to an established ambient range, or both, may be required.

7.1.4 The geometry, mass, and thickness of the reference standard and test specimen shall be controlled within limits that will permit sorting.

7.1.5 Magnetic permeability variations can interfere when sorting paramagnetic materials.

7.1.6 Signal response can result from a change in relative motion between the test specimen and the test coil, such as the length of time the specimen is in a test coil (see 4.4).

7.1.7 Conductivity has an unambiguous relationship to hardness for certain alloys. However, when alloys are mixed, identical conductivity does not necessarily indicate the same hardness.

7.1.8 Care must also be exercised in using conductivity to sort overheated parts quenched at a high temperature as the conductivity reading for acceptable parts may repeat at a large increase in temperature.

7.1.9 Lift-off can result in a change in the test system output with probe coils. This effect is a change in the magnetic coupling between the test specimen and probe coil. Care must be exercised to prevent this effect from interfering with examination results; either mechanical or electronic compensation must be used.

7.1.10 For certain heat-treatable (aluminum) alloys, conductivity values can also repeat themselves during the aging cycle at a constant temperature. Thus, for such alloys, conductivity is not unique as a monitor of temper, etc.

8. Apparatus

8.1 *Electronic Apparatus*—The electronic apparatus shall be capable of energizing the test coils with alternating currents of suitable frequencies and power levels and shall be capable of sensing changes in the electromagnetic response of the coils. Equipment may include any suitable signal-processing devices (phase discriminator, filter circuits, etc.) and the output may be displayed by meter, oscilloscope, recorder, signaling devices, or any suitable combination required for the particular application.

8.2 Test coils may be of the encircling or probe-coil type and shall be capable of inducing an electromagnetic field in the test specimen and reference standard, and sensing changes in the electric or magnetic characteristics of the test specimen.

8.2.1 When selecting the test coil, the objective should be to obtain a coil fill factor as large as possible. This means that the inside of the test coil should be filled by the test specimen as much as possible. This is of primary importance for examinations requiring high sensitivity.

8.2.2 For complicated test specimen shapes, a corresponding insert shall be provided to ensure that each test specimen can be placed in the same position within the test coil. These inserts, as well as any other accessories, should consist of non-ferromagnetic, electrically nonconductive material.

8.3 *Mechanical Handling Apparatus*— A mechanical device for feeding and sorting the test specimens may be used to automate a particular application.

9. Sampling

9.1 Sampling (see Practices E105 and E122) is a method to obtain assurance that materials are of satisfactory quality. Instead of 100 % inspection, a portion of the material is examined to show evidence of the quality of the whole. There are two important needs for this approach: first, the final inspection or examination is made to assure that products delivered are in conformance with specification requirements; second, to control parts and assemblies while they are being processed. Statistical acceptance sampling tables and statistical process-control sampling tables have been developed to meet these needs.

9.2 Acceptance sampling may be conducted on an accept/reject (or attributes) basis; that is, determining whether or not the units of the sample meet the specification. Examination of the samples may also be conducted on a measurements (or variables) basis; that is, determining actual readings on the units in the sample. The majority of acceptance sampling is carried out on a sampling by attributes basis and the usual acceptance sampling table is designed for accept/reject.

9.3 Process control sampling may be conducted on material during the course of production to prevent large quantities of defective parts being found in the acceptance examinations. Many parts and materials are subjected to several successive machining or processing operations before they become finished units. Parts can be most effectively controlled during production by examining small samples of these parts at frequent regularly scheduled intervals. The object of this process check is to provide a continuous picture of the quality of parts being produced. This helps prevent production of defective parts by stopping and correcting the problem as soon as it begins to appear in the manufacturing process and thereby keeping the process in control. Sampling may be by attributes or by variables and process control sampling tables are used. The measurements (variables) control chart is by far the most effective process control technique.

9.4 Statistical sampling tables have four definite features: *(1)* specification of sampling data—that is, the size of the samples to be selected, the conditions under which the samples are to be selected, and the conditions under which the lot will be accepted or rejected; *(2)* protection afforded—that is, the element of risk that the sampling schedules in a given table will reject good lots or accept bad ones; *(3)* disposal procedure—that is, a set of rules that state what is to be done with lots after sampling has been completed; and *(4)* cost required—that is, average inspection cost required to accept or reject a lot.

10. Reference Standards

10.1 Two reference standards of the precise size and configuration of the product to be examined are usually used to set up for sorting by the absolute coil method (see 11.2). Three reference standards of the precise size and configuration are usually used for sorting by the comparative coil (see 11.3) method.

10.2 Three reference standards are usually required for a three-way mix (see 11.4).

10.3 The reference standard should be selected to represent the extremes of acceptable and unacceptable groups or a range of hardness or conductivity to assure no overlap in the sort.

10.4 Other arrangements can be used and are acceptable but are not described in this procedure.

11. Standardization

11.1 The electromagnetic sorting method is primarily one of comparison between specimens. Empirical data and physical examinations on samples representing properties to be separated determine the validity of the sort. The standardization procedure shall be based on the properties of the sample requiring separation. The sort may require more than one operation.

11.2 When using the absolute coil method (encircling), insert the reference standard to a fixed position in the coil and adjust the test instrument to get an on-scale meter or oscilloscope reading, or both. Replace the acceptable reference standard with a known unacceptable reference standard in the same exact position and adjust the sensitivity of the instrument to maximize the indicated difference reading without exceeding 90 % of the available scale range.

11.3 When using the comparative coil method (encircling), select a reference piece (usually one that falls within the acceptable limits of the specimens being examined), place it in the reference coil and set this coil and piece in a location so that it will not be accidentally disturbed during the sorting operation. For this method, when used with a two-way mix, choose two reference standards, one of which represents the acceptable and the other the unacceptable group. Place the acceptable reference standard at a fixed position in the test coil coinciding with the position of the reference piece in the reference coil and balance the instrument. Replace this acceptable reference standard with one representing the unacceptable group and adjust the test instrument's phase, sensitivity, and coil current, to maximize the indicator reading without exceeding 90 % of the available scale range. Reinsert the acceptable reference standard and alternately readjust the instrument controls to retain a null value for the acceptable reference standard and maximum indication for the unacceptable reference standard.

11.4 For a three-way sort, it is best to have three reference standards, two of which represent the high and low limits of acceptability for one group or one each of the two unacceptable groups. The third reference standard represents the acceptable lot of material.

11.4.1 A typical case of high and low limits of acceptability reference standards is in measurements where reference standards representing maximum and minimum acceptable hardness are required. In this instance, insert the third reference standard representing the acceptable lot into the test coil and adjust the instrument for a null or zero reading. Then adjust the controls to maximize the indications without exceeding ±90 % of the available scale range from the null for each of the other two reference standards (maximum and minimum). Alternate readjustment of the controls may be necessary to retain the null reading, as well as the maximum and minimum limits for acceptance.

11.4.2 For a three-way sort when three dissimilar grades of material become mixed, place the third reference standard (acceptable group) into the test coil and null. Then successively insert into the test coil the two reference standards representing the other two grades and adjust the instrument's controls to maximize the indications without exceeding ±90 % of the available scale range from the null for each of the other two reference standards. Alternate readjustment of the controls may be necessary to retain the null reading as well as the indication for the other two reference standards.

11.5 A similar procedure to that used with encircling coils is used with probe coils (11.2 – 11.4). Instead of placing reference standards in the coil(s), position the probe(s) in a suitable location on the reference standard(s).

12. Procedure

12.1 Connect the required test coil to the instrument. Place insert(s) or other positioning fixture in the coil(s) if required.

12.2 Switch on the instrument and allow it to warm up for at least the length of time recommended by the manufacturer.

12.3 Make all necessary setup and control adjustments in accordance with the manufacturer's recommendation. Adjust frequency, field strength, sensitivity, and other necessary controls to values determined for the electromagnetic sort.

12.4 Standardize the sorting system in accordance with 11.2 when using the absolute coil method, 11.3 when using the comparative coil method, or 11.5 when using probe coils. Standardize at the start of the examination run and at least once every hour of continuous operation or whenever improper functioning of the system is suspected (see 12.7).

12.5 For manual operation, insert the test specimens manually in the test coil.

12.5.1 Read the results on an indicator.

12.5.2 Manually remove the specimens from the test coil.

12.6 For automatic sort, transmit the test specimens continuously through the test coil.

12.6.1 In passing through the coil, each test specimen is analyzed by the test instrument.

12.6.2 A signal, corresponding to the conductivity of the respective test specimen, is sent to a sorting gate where the specimens are automatically sorted into preselected groups.

12.7 Verify the standardization of the instrument at the end of examining each lot. If the standardization is found to have changed since the last check so that it affects the sort, restandardize the system and reexamine all of the material examined since the last check.

13. Interpretation of Results

13.1 The results of most nondestructive evaluation procedures are based on the comparison of an unknown with a reference standard. Unless the significant interrelationships of material or product properties are understood and measurable for both standard and unknown samples, erroneous examination results may be obtained.

13.2 Electromagnetic sorting is best used for repetitive examinations on material that has the same shape, composition, and metallurgical structure; that is, it is not generally used for examinations on grossly different materials. Electromagnetic sorting is generally not useful if there is limited knowledge of the properties of the unknown or material to be examined.

13.3 Interpretation of data depends upon the degree to which the materials to be examined compare with the reference materials. It is necessary to have all variables, except that one selected as a basis for sorting, under control if the measured variation is to be properly interpreted. Results can often be interpreted or explained by a processing change, such as temperature, composition, and inclusions, when the measured property is known to be a function of the processing procedure.

13.4 When products with different shapes, alloys, or conductivities are to be sorted, only a qualitative interpretation of results can be made. The materials can be said to be different, but the reason for the difference may not be understood.

13.5 When the spread in value of the measured variable is sufficient, electromagnetic sorting can be 100 % effective. However, there may be cases where a single examination will not show a clear separation. Often a second examination or procedure can be used to further define the separation of materials. For example, a different examination frequency may show the effect of a second variable.

13.6 Shape and surface variations can mask the examination results. If surface hardness is desired as the basis for sorting, all material should have composition and surface roughness under sufficient control so that the effects of variations in hardness can be separated.

13.7 Measurement bias depends upon factors that include equipment, techniques, temperature control of parts and reference standard, geometry, types of materials, and operator. Variations in these factors can affect the bias of the sort.

14. Report

14.1 The written report of an electromagnetic sort should contain any information about the examination setup that will be necessary to duplicate the examination at the same or some other location, plus such other items as may be agreed upon by the using parties. The following information should be recorded:

14.1.1 Description of apparatus:

14.1.1.1 Type of equipment.

14.1.1.2 Model number.

14.1.1.3 Serial number.

14.1.2 Output Device (if used):

14.1.2.1 Type.

14.1.2.2 Model number.

14.1.2.3 Serial number.

14.1.3 Coil:

14.1.3.1 Size.

14.1.3.2 Type.

14.1.4 Other interconnecting apparatus.

14.1.5 Reference standards.

14.1.6 Examination frequency.

14.1.7 Description of materials:

14.1.7.1 Geometry.

14.1.7.2 Chemistry.

14.1.7.3 Heat treatment.

14.1.8 Method of standardization.

14.1.9 Scanning speed.

14.1.10 Temperature of the reference standard.

14.1.11 Temperature of the test specimen.

14.1.12 Examination method.

15. Keywords

15.1 encircling coils; electromagnetic sorting; nonferrous metals; probe coils; sorting

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E703–09) that may impact the use of this standard.

(1) Section 3 renamed "Terminology" for consistency in other ASTM documents.
(2) Section 6 revised to add ISO 9712 as per P10 policy.
(3) Section 10 renamed "Reference Standards" and reworded "samples" and "known samples" to "reference standards."
(4) Inserted the word "reference" in front of "standard" in Sections 4, 7, 8, 11, 13, and 14.
(5) Section 15 revised to update document.