Designation: E 566 – 99

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

This standard is issued under the fixed designation E 566; 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 procedure for sorting ferrous metals using the electromagnetic (eddy-current) method. The procedure relates to instruments using absolute or comparator-type coils for distinguishing variations in mass, shape, conductivity, permeability, and other variables such as hardness and alloy that affect the electromagnetic or magnetic properties of the material. The selection of samples to determine sorting feasibility and to establish standards is also included.[2]

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:*

E 105 Practice for Probability Sampling of Materials[3]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[3]

E 543 Practice for Agencies Performing Nondestructive Testing[4]

E 1316 Terminology for Nondestructive Examinations[4]

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practice for Qualification and Certification in Nondestructive Testing[5]

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel[5]

2.3 *Federal Standard:*

NAS-410 Nondestructive Testing Personnel Qualification and Certification[6]

3. Terminology

3.1 Standard terminology relating to electromagnetic examination may be found in Terminology E 1316, Section C: Electromagnetic Testing.

4. Summary of Practice

4.1 The two techniques that are primarily used in electromagnetic sorting employ the absolute (single-) and comparative (two-) coil methods. The decision of whether to use single-coil or two-coil operation is usually determined by empirical data. In the absolute-coil method, the equipment is standardized by placing standards of known properties in the test coil. The value of the tested parameter (for instance, hardness, alloy, or heat treatment) is read on the scale of an indicator. In the comparative-coil method, the test piece is compared with a reference piece and the indication tells whether the piece is within or outside of the required limits.

4.1.1 *Absolute Coil Method*—A sample of known classification is inserted in the test coil, and the controls of the instrument are adjusted to obtain an indication. The test is then continued by inserting the pieces to be sorted into the test coil, and observing the instrument indication.

4.1.2 *Comparative Coil Method*—Known reference pieces representing the minimum or maximum limits of acceptance, or both, are inserted in the reference coil and test coil. The instrument controls are adjusted for appropriate indications. The test is then continued by inserting the pieces to be sorted in the test coil, leaving a known reference in the reference coil, and observing the instrument indication.

4.2 The range of instrument indication must be so adjusted in the initial step that the anticipated deviations will be recognized within the range of readout according to whether two- or three-way sorts are to be accomplished.

4.3 Both absolute and comparative methods require comparing the pieces to be tested with the reference piece(s). Two or more samples representing the limits of acceptance may be required. In the absolute method the electrical reference is generated by a test piece. In the comparative method any electromagnetic condition that is not common to the test specimen and the standard will produce an imbalance in the system. The comparative method usually is more stable, as it normally suppresses noise.

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[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 Methods.

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[2] General information can be found in the *Nondestructive Testing Handbook*, (Second Edition), Vol IV: Electromagnetic Testing, Society for Nondestructive Testing, 1986.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228–0518.

[6] Available from Standardization Documents Order Desk, Building 4, Section D, 700 Robbins Avenue, Philadelphia, PA 19111–5904, ATTN: NPODS.

4.4 The testing process may consist of manual insertion of one piece after another into the test coil, or an automated feeding and classifying mechanism may be employed. In automated setups, it is sometimes necessary to stop each piece momentarily in the test coil while the reading is being taken, especially if low test frequencies are employed.

5. Significance and Use

5.1 Absolute and comparative methods provide a means for sorting large quantities of ferrous parts of stock with regard to composition, condition, structure, or processing, or a combination thereof.

5.2 The comparative or two-coil method is used when high-sensitivity testing is required. The advantage of this method is that it almost completely suppresses all internal or external disturbances such as temperature variations or stray magnetic fields. The two-coil method is normally used when harmonic evaluation is employed for sorting.

5.3 The ability to accomplish satisfactorily these types of separations is dependent upon the relation of the magnetic characteristics of the ferromagnetic 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 testing may approach ten pieces per second depending on their size and shape.

5.5 The success of sorting ferromagnetic material depends mainly on the proper selection of magnetic field strength and frequency of signal in the test coil, fill factor, and variables present in the sample.

5.6 The degree of accuracy of a sort will be affected greatly by the coupling between the test coil field and the tested part and the accuracy with which the tested part is held in the test coil field during the measuring period.

5.7 When high currents are used in the test coil, a means should be provided to maintain a constant temperature of the test standard in order to minimize measurement drift.

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 NDT personnel qualification practice or standard, such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, 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 Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 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 specific influence of the following variables must be considered for proper interpretation of the results obtained:

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

7.1.2 In sorting magnetic materials, a magnetic field strength and test frequency must be used that will result in a well-defined separation of variables being tested.

7.1.3 When examining magnetic materials at low field strength, any influence from the previous magnetic history of the part on the test (residual magnetism) shall be negated by demagnetization of the part if it restricts the electromagnetic sort.

7.1.4 The temperature of the standard and test part 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 test standard when high field strengths are used or allowing test parts to cool or heat to an established ambient range, or both, may be required.

7.1.5 The geometry and mass of the standard and test part shall be controlled within limits that will permit sorting.

7.1.6 *Speed Effects*—See 4.4.

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 the 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, scope, 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 electromagnetic field in the test specimen and standard and sensing changes in the electric and 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 piece as much as possible. This is of primary importance for tests requiring high sensitivity.

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

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

9. Sampling

9.1 Sampling (see Practices E 105 and E 122) 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, in the final inspection or tests made to ensure that products delivered are in conformance with specification requirements; second, to control parts and asemblies 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 the attributes basis and the usual acceptance sampling table is designed for accept/reject criteria.

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 tests. 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 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 variable and process control sampling tables. The measurements (variables) control chart is by far the most effective process control technique.

9.4 Statistical sampling tables have four definite features: (*1*) specifications 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. Test Specimen or Sample (Standards)

10.1 A known acceptable sample and known unacceptable sample of the precise size and configuration of the product to be tested shall be used to set up for sorting by the absolute coil (see 11.2) or comparative coil (see 11.3) method.

10.2 Three known samples are required for a three-way mix (see 11.4).

10.3 The sample should be selected to represent the extremes of acceptable and unacceptable groups to assure no overlap in the sort.

11. Standardization

11.1 The electromagnetic sorting method is primarily one of comparison between pieces. Empirical data and physical tests determine classification. The standardization procedure shall be governed by the properties of the sample requiring separation.

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

11.3 When using the comparative coil method, select a reference piece (usually one that falls within the acceptable limits of the pieces being tested) and place it in the reference coil in such a way that it will not be disturbed, and set this coil and reference piece out of the way. For this method, when confronted with a two-way mix, choose two standards, one of which represents the acceptable and the other the unacceptable group. Place the acceptable standard to 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 calibration standard with one representing the unacceptable group and adjust the test instrument's phase, sensitivity, and coil current; then index to maximize the indicator reading without exceeding 90 % of the available scale range. Reinsert the acceptable standard and alternately readjust the instrument controls to retain a null value for the acceptable standard and maximum indication for the unacceptable standard.

11.4 For a three-way sort, it is best to have three 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 standard, of course, represents the acceptable lot of material.

11.4.1 A typical case for the former usually consists of hardness or case depth measurements where standards representing maximum and minimum limits are required. In this instance, insert the third 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 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 standard (acceptable group) into the test coil and null. Then successively insert into the test coil the two 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 standards. Alternate readjustment of the controls may be necessary to retain the null reading as well as the indication for the other two standards.

11.5 When high current is used in the comparative testing method, the reference piece is likely to heat up, which will change its magnetic properties. It is necessary to provide for cooling or to have several identical reference pieces so that they can be interchanged to prevent drift in the balance point.

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 or 11.3 when using the comparative coil method. Standardize at the start of the test run and at least once every hour of continuous operation or whenever improper functioning of the system is suspected.

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

12.5.1 Read the test results on an indicator.

12.5.2 Manually remove the pieces from the test coil.

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

12.6.1 Each test piece in passing through the coil is analyzed by the test instrument.

12.6.2 A signal, corresponding to the quality of the respective test piece, is sent to a sorting gate where the tested pieces are automatically sorted into preselected quality groups.

12.7 Verify the calibration of the instrument at the end of testing each lot. If the standardization is found to have changed since the last check so that it affects the sort, retest after standardization all of the material tested since the last check.

13. Interpretation of Results

13.1 The results of any nondestructive testing procedure are based on the comparison of an unknown with a standard. Unless all of the significant interrelationships of material or product properties are understood and measurable for both standard and unknown samples, the test results may be meaningless.

13.2 Electromagnetic sorting is best used for repetitive tests on material "identical" in shape, composition, and metallurgical structure, and not for tests on grossly different materials. Electromagnetic sorting is generally not useful if there is limited knowledge of the properties of the unknown or test material.

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

13.4 When products grossly different in shape, alloy, permeability, or conductivity are to be measured, only a general interpretation of results can be made. The materials can be said to be different, but the how and the why of the difference usually is not determinable.

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 test will not show a clear separation. Often a second test or procedure can be used to further define the separation of materials. For example, a change in test frequency may show the effect of a second variable.

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

14. Report

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

14.1.1 *Description of Apparatus*:

14.1.1.1 Type of equipment.

14.1.1.2 Model No.

14.1.1.3 Serial No.

14.1.2 *Output Device*:

14.1.2.1 Type.

14.1.2.2 Model No.

14.1.2.3 Serial No.

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 *Test Frequency*.

14.1.7 *Description of Materials*:

14.1.7.1 Geometry.

14.1.7.2 Chemistry.

14.1.7.3 Heat treatment.

14.1.7.4 Conductivity range.

14.1.8 *Method of Calibration*.

14.1.9 *Field Strength*.

14.1.10 *Scanning Speed*.

14.1.11 *Temperature of the Standard*.

14.1.12 *Temperature of the Test Sample*.

14.1.13 *Sample Demagnetized*.

14.1.14 *Test Method*.

15. Precision and Bias

15.1 Measurement bias depends upon factors including the equipment, techniques, control of temperature of parts and standard, geometry, magnetic history of the part, field strength used, types of materials, and operator variables. Variations in these factors can affect the bias of the sort. Results in the majority of sorts can be expected to be quite accurate, with a single combination of the above factors and selection of a point on the magnetization curves (field strength) at which each curve is displaced from its nearest neighbor by a substantial distance (probably within a 1 % tolerance). The field strength is usually determined empirically and the care with which it is determined will affect the precision and bias.

16. Keywords

16.1 absolute coil; comparator coils; electromagnetic sorting; sorting