Designation: A 876 – 03

Standard Specification for Flat-Rolled, Grain-Oriented, Silicon-Iron, Electrical Steel, Fully Processed Types [1]

This standard is issued under the fixed designation A 876; 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 specification covers the detailed requirements to which the specified grades of flat-rolled, grain-oriented, fully processed electrical steels shall conform. These steels are used primarily in transformer cores operating at moderate to high magnetic flux densities at commercial power frequencies (50 and 60 Hz).

1.2 These grain-oriented electrical steels are low-carbon, silicon-iron alloys with a silicon content of approximately 3.2 % in which low core loss and high permeability in the direction of rolling have been achieved by appropriate metallurgical processing.

1.3 The electrical-steel grades described in this specification include (*1*) conventional grain-oriented electrical steel tested at 15 kG (1.5 T) in accordance with Test Method A 343/A 343M, (*2*) conventional grain-oriented electrical steel tested at 17 kG (1.7 T) in accordance with Test Method A 343/A 343M, (*3*) high-permeability grain-oriented electrical steel tested at 17 kG (1.7 T) in accordance with Test Method A 343/A 343M, and (*4*) laser-scribed high-permeability grain-oriented electrical steel tested at 17 kG (1.7 T) in accordance with Test Methods A 804/A 804M.

1.4 The values stated in customary (cgs-emu and inch-pound) units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units, which are provided for information only and are not considered standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 34/A 34M Practice for Sampling and Procurement Testing of Magnetic Materials

A 340 Terminology of Symbols and Definitions Relating to Magnetic Testing

A 343/A 343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame

A 345 Specification for Flat-Rolled Electrical Steels for Magnetic Applications

A 664 Practice for Identification of Standard Electrical Steel Grades in ASTM Specifications

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment

A 717/A 717M Test Method for Surface Insulation Resistivity of Single-Strip Specimens

A 719/A 719M Test Method for Lamination Factor of Magnetic Materials

A 721 Test Method for Ductility of Oriented Electrical Steel

A 804/A 804M Test Methods for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Sheet-Type Test Specimens

A 937/A 937M Test Method for Determining Interlaminar Resistance of Insulating Coatings Using Two Adjacent Test Surfaces

A 976 Classification of Insulating Coatings by Composition, Relative Insulating Ability and Application

3. Terminology

3.1 The terms and symbols used in this specification are defined in Terminology A 340.

4. Classification

4.1 The ASTM core-loss type designations, formulated in accordance with Practice A 664, for grain-oriented electrical steels covered by this specification are listed in Table 1.

5. Condition

5.1 These grain-oriented electrical steels may be purchased in any of the following conditions (which are combinations of material form and surface type or treatment) as desired for the expected end use.

[1] This specification is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.02 on Material Specifications.

This specification replaces A 665, A 725, and A 843.

Current edition approved Oct. 1, 2003. Published November 2003. Originally approved in 1987. Last previous edition approved in 1998 as A 876/A 876M – 98.

[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.

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TABLE 1 Core-Loss Type Designations

Conventional Grain-Oriented Electrical Steel
Tested at 15 kG (1.5 T) in Accordance with Test Method A 343/A 343M

ASTM Core-Loss Type[A]	Aim Thickness,[B] in. (mm)	Maximum Specific Core Loss,[C] W/lb (W/kg)	
		60 Hz	50 Hz
18G041	0.0070 (0.18)	0.41 (0.90)	0.31 (0.68)
23G045	0.0090 (0.23)	0.45 (0.99)	0.34 (0.75)
27G051	0.0106 (0.27)	0.51 (1.12)	0.39 (0.85)
30G058	0.0118 (0.30)	0.58 (1.28)	0.44 (0.97)
35G066	0.0138 (0.35)	0.66 (1.46)	0.50 (1.11)

Conventional Grain-Oriented Electrical Steel
Tested at 17 kG (1.7 T) in Accordance with Test Method A 343/A 343M

ASTM Core-Loss Type[A]	Aim Thickness,[B] in. (mm)	Maximum Specific Core Loss,[C] W/lb (W/kg)	
		60 Hz	50 Hz
23H070	0.0090 (0.23)	0.70 (1.54)	0.53 (1.17)
27H074	0.0106 (0.27)	0.74 (1.63)	0.56 (1.24)
30H083	0.0118 (0.30)	0.83 (1.83)	0.63 (1.39)
35H094	0.0138 (0.35)	0.94 (2.07)	0.71 (1.57)

High-Permeability Grain-Oriented Electrical Steel
Tested at 17 kG (1.7 T) in Accordance with Test Method A 343/A 343M

ASTM Core-Loss Type[A]	Aim Thickness,[B] in. (mm)	Maximum Specific Core Loss,[C] W/lb (W/kg)	
		60 Hz	50 Hz
23P060	0.0090 (0.23)	0.60 (1.32)	0.46 (1.01)
27P066	0.0106 (0.27)	0.66 (1.46)	0.50 (1.11)

Laser-Scribed High-Permeability Grain-Oriented Electrical Steel
Tested at 17 kG (1.7 T) in Accordance with Test Methods A 804/A 804M

ASTM Core-Loss Type[A]	Aim Thickness,[B] in. (mm)	Maximum Specific Core Loss,[D] W/lb (W/kg)	
		60 Hz	50 Hz
23Q054	0.0090 (0.23)	0.54 (1.19)	0.41 (0.90)
27Q057	0.0106 (0.27)	0.58 (1.28)	0.44 (0.97)

[A] See Practice A 664.
[B] These shall be the overall thicknesses as measured by contacting micrometre caliper.
[C] Based on parallel-grain Epstein specimens, stress-relief annealed after shearing in accordance with 14.1.2.
[D] Based on as-sheared parallel-grain sheet-type specimens. Stress-relief annealing will nullify the core-loss reduction produced by the laser scribing.

5.1.1 *Condition NF*—An annealed coil form having an inorganic surface coating, Type C-2 (Note 1). This material is not flattened and so exhibits appreciable coil curvature. The principal application is in spirally wound or formed cores in which the strip curvature is not detrimental to fabricating procedures or device performance.

5.1.2 *Condition F2*—Thermally flattened sheet or coiled strip having an inorganic surface coating, Type C-2, plus a thinner (compared to Condition F5) inorganic coating, Type C-5, applied over the inherent C-2 coating. The principal application is in spirally wound or formed cores in which strip curvature would be detrimental to fabricating procedures.

5.1.3 *Condition F5*—Thermally flattened sheet or coiled strip having an inorganic surface coating, Type C-2, plus an inorganic coating, Type C-5, applied over the inherent C-2 coating to provide extra surface insulation resistance. The principal application is in flat sheared laminations for cores of power transformers.

5.1.4 *Condition PQ*—Thermally flattened sheet or coiled strip (sometimes called “punching quality”) with the inherent C-2 coating removed and an inorganic coating, Type C-5, applied for insulative purposes. The principal application is in flat stamped laminations for small stacked cores with only moderate surface insulation requirements.

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NOTE 1—Additional description of surface coating Types C-2 and C-5 is presented in Specification A 345 and Classification A 976.

5.2 Core-loss types having code letters P and Q are available only in Condition F5.

6. Ordering Information

6.1 Orders for material under this specification shall include such of the following information as is required to describe the material adequately:

6.1.1 ASTM specification number,

6.1.2 ASTM core-loss type designation (Table 1),

6.1.3 Material condition (form and surface type) designation (5.1),

6.1.4 Ductility class (when required),

6.1.5 Sheet or strip width,

6.1.6 Length (only when cut lengths are specified),

6.1.7 Total weight of each ordered item,

6.1.8 Limitations on lift weight,

6.1.9 Limitations on coil size,

6.1.10 *End Use* (Whenever practicable, the user should specify whether the ordered material will be made into flat sheared laminations, flat stamped laminations, wound cores, bonded wound cores, formed lamination cores, welded lamination cores, and so forth. This will help the producer to provide the most suitable material for the user's fabricating practices), and

6.1.11 Exception to the specification or special requirements.

7. Materials and Manufacture

7.1 Normally, these steels contain approximately 3.2 % silicon and the balance iron with residual elements at a minimum. When requested, the producer shall provide a statement of chemical composition typical of the material being supplied.

7.2 These electrical steels may be made by the basic-oxygen or electric-furnace process.

7.3 When changes in the manufacture of successive shipments of the material are believed to increase the likelihood of adverse effects upon the magnetic performance or fabrication for the specified end use, the producer shall notify the user as soon as possible before shipment is made so that he can be afforded an opportunity to evaluate the effects.

8. Magnetic Properties

8.1 *Core Loss*:

8.1.1 Maximum permissible specific core losses at 15 or 17 kG (1.5 or 1.7 T), 50 and 60 Hz, are guaranteed and are listed in Table 1 for the ASTM core-loss types. The sampling, specimen preparation, and testing practices that are described herein must be followed when conformity to these guarantees is being checked.

8.1.2 Material that conforms to both the core-loss and thickness limits of this specification shall be identified by this specification number and the appropriate core-loss designation.

8.2 *Permeability*:

8.2.1 The permeability at all magnetic flux densities shall be as high as practicable. The quality control of these grades is normally based on a measurement of relative peak permeability, μ_p, at a peak ac magnetic field strength, H_p, of 10 Oe (796 A/m). For the conventional grain-oriented grades, the value of relative μ_p at 10 Oe (796 A/m) is commonly above 1800. For the high-permeability grades, it is commonly above 1880.

8.3 *Magnetic Aging*:

Although the magnetic properties of these electrical steels are considered to be stable, the maximum core-loss values of Table 1 are based on tests of non-aged specimens. The guarantee of magnetic properties after an aging treatment is subject to negotiation between the user and the producer.

9. Surface Insulation Characteristics

9.1 The surfaces types produced in each of the material conditions of 5.1 normally have different levels of insulating ability. Interlaminar resistance of two adjacent test surfaces is determined with Test Method A 937/A 937M. Surface insulation resistivity of a single test surface is determined with Test Method A 717/A 717M. Typical ranges for surface insulation effectiveness of the various surface types are given in Appendix X1.

9.2 When insulative characteristics substantially different than those listed in Appendix X1 are necessary, the specific requirements and the procedures for evaluating them shall be negotiated between the user and the producer.

10. Physical and Mechanical Properties

10.1 *Lamination Factor*—The lamination factor shall be as high as practicable consistent with the material thickness and condition. Lamination factor may be determined using Test Method A 719/A 719M. Typical lamination factor values for the various material thickness and condition combinations are shown in Appendix X1.

10.2 *Ductility*—The ductility shall be as high as practicable. When the application requires forming around a sharp radius during fabrication, and an evaluation of the ductility is required, the ductility rating shall be determined in accordance with Test Method A 721. Ductility ratings in the following classes are appropriate for grain-oriented steels in any thickness and condition when tested at room temperature with a bend transverse to the rolling direction with "as-sheared" specimens:

Ductility Class	Permissible Number of Fractures at Bend [A]
1	none
2	1 or 2, total length not over 0.5 in. (12.7 mm)
3	3 to 8

[A] Based on 24- to 36-in. (610- to 910-mm) width of material. For widths less than 24 in. (610 mm), the number of permissible fractures should be reduced in proportion to the ratio of the width to 24 in. (610 mm).

11. Dimensions and Permissible Variations

11.1 *Thickness*—The aim thicknesses of the ASTM core-loss types are listed in Table 1.

11.1.1 *Thickness Variations*—The thickness measured at any location not less than 0.4 in. (10 mm) from an edge shall not deviate more than ±0.001 in. (±0.025 mm) from the average thickness of the test lot or coil. The outer limits of acceptable thickness of the ASTM core-loss type shall be as shown in Table 2.

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TABLE 2 Thickness Tolerances

ASTM Core-Loss Type	Thickness Limits, in. (mm)
18G041	0.0060-0.0080 (0.152–0.203)
23G045, 23H070, 23P060, 23Q054	0.0075-0.0100 (1.190-0.254)
27G051, 27H074, 27P066, 27Q057	0.0095-0.0120 (0.241-0.305)
30G058, 30H083, 30P070	0.0105-0.0130 (0.267-0.330)
35G066, 35H094	0.0125-0.0150 (0.318-0.381)

11.2 *Width Tolerances*—The width of material supplied, either as coils or cut lengths, shall be as close as possible to the ordered width, but in no case shall the maximum deviations from the specified width exceed the values given in Table 3.

11.3 *Length Tolerances*—The length dimension of cut lengths shall be as close as practicable to the ordered length. The maximum deviations from ordered length shall be as shown in Table 4.

11.4 *Camber (Full-Width Coils)*—The deviation of a side edge from a straight line over a 96-in. (2440-mm) length or fraction thereof shall not exceed 0.125 in. (3.2 mm).

11.5 *Out of Square (Cut Lengths)*—The deviation of an end edge from a straight line placed at a right angle to the side, touching one corner and extending to the other side, shall not exceed 0.0625 in./6 in. (1.6 mm/152 mm) of width or fraction thereof.

12. Workmanship, Finish and Appearance

12.1 *Flatness*:

12.1.1 Sharp, short waves and buckles are extremely detrimental to the effective use of grain-oriented electrical steels in flat laminations and shall be avoided in the delivered product.

12.1.2 The user shall inform the producer of any requirements for a degree of flatness more critical than that provided by the usual commercial practices. Procedures for judging or evaluating the degree of flatness in such cases shall be subject to negotiation between the user and the producer.

12.2 *Surface Defects*—The surface of the material shall be reasonably clean and essentially free from manufacturing defects such as holes, mill marks, slivers, and so forth, which would interfere with its effective use in the intended application. The surface shall be free of loose dust and be compatible with immersion in the usual liquid transformer coolants. Applied surface coatings shall be reasonably thin, continuous in coverage, and tightly adherent.

13. Sampling

13.1 Each test lot shall be a single full-width coil constituting the finished product of a single hot-rolled band processed under essentially uniform conditions. The weight of a test lot is typically less than 20 000 lb (9000 kg). The producer shall assign a serial number to each test lot for identification.

13.2 Test samples shall be obtained from both ends of the full-width coils after the final heat treatment.

TABLE 3 Width Tolerances[A]

Specified Width, in. (mm)	Width Tolerances, in. (mm)	
	Over	Under
To 4 (102), incl.	0.005 (0.127)	0.005 (0.127)
Over 4 (102) to 9 (229), incl	0.007 (0.178)	0.007 (0.178)
Over 9 (229) to 15 (381), incl	0.010 (0.254)	0.010 (0.254)
Over 15 (381)	0.016 (0.406)	0.016 (0.406)

[A] The purchaser should make it clear on his purchase order whenever a specific maximum or minimum acceptable width rigidly applies so that the producer can take the sum of the over and under tolerances into account on either the "under" or "over" side as required.

TABLE 4 Length Tolerances

Specified Length, in. (mm)	Length Tolerances, in. (mm)	
	Over	Under
Over 60 (1520) to 96 (2440), incl	0.5 (12.7)	0 (0)
Over 96 (2440)	0.75 (19.1)	0 (0)

14. Specimen Preparation

14.1 *Epstein Specimens*:

14.1.1 Core-loss types having code letters G, H, and P require preparation of Epstein test specimens representing each end of each full-width coil (or test lot). The specimen preparation shall be in accordance with Test Method A 343/A 343M. All test strips shall be cut with the long dimension parallel to the rolling direction.

14.1.2 Each Epstein test specimen shall be stress-relief annealed before testing. The objective of this specimen anneal is to eliminate the destructive effects of cold working incurred in obtaining the test specimen and to ensure that its magnetic characteristics are like those inherent in the material from which it was taken. The stress-relief anneal shall be made under conditions that ensure that the specimen strips reach a temperature of about 1450 to 1550°F (790 to 840°C) for approximately 1 h in an atmosphere comprised of a combination (Note 2) of pure nitrogen and pure hydrogen. The dew point of the atmosphere within the annealing chamber shall be no higher than 0°F (−18°C). Provision must be made for obtaining essentially perfect flatness in the Epstein specimen in the stress-relief anneal.

NOTE 2—To prevent any chemical change in the test specimen or the insulative coating, atmosphere combinations comprised of pure dry nitrogen with additions of 2 to 15 % of pure dry hydrogen are preferred. Exothermic atmospheres produced from petroleum gases are not suitable for evaluation of the properties of these materials unless the carbon monoxide and carbon dioxide components are removed so that they are equivalent to pure nitrogen + hydrogen mixtures.

14.2 *Sheet-Type Specimens*:

14.2.1 Core-loss types having code letter Q require preparation of sheet-type test specimens representing each end of each full-width coil (or test lot). The specimen preparation shall be in accordance with Test Methods A 804/A 804M. All sheet-type test specimens shall be cut with the rolling direction parallel to the intended test direction.

14.2.2 The sheet-type test specimens shall not be stress-relief annealed before testing. Stress-relief annealing will nullify the core-loss reduction produced by the laser scribing.

15. Test Methods

15.1 The required tests for core loss shall be performed in accordance with Test Method A 343/A 343M for core-loss types having code letters G, H, and P.

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15.2 The required tests for core loss shall be performed in accordance with Test Methods A 804/A 804M for core-loss types having code letter Q.

15.3 In all testing of these materials, the density shall be presumed to be 7.65 g/cm^3 (7650 kg/m^3) in accordance with Practice A 34/A 34M.

16. Test Report

16.1 The producer shall submit to the user, as promptly as possible after shipment, a certified report of the core-loss value for each test lot as measured in accordance with Sections 13, 14, and 15 to show that the material conforms to this specification. The test methods and applicable test conditions shall be clearly stated. The report also shall carry the shipping lot identification, purchase order number, and such other information as may be needed to identify the test values with the proper shipment and shipping lot.

16.2 The core-loss value assigned to the test lot shall be the higher value of the coil end tests made in compliance with Sections 13, 14, and 15. This test value shall apply to all portions of the test lot whether shipped as a wide coil, cut lengths, or narrow width coils cut from the wide coil.

16.3 When a shipping lot is comprised of two or more test lots, the assigned core-loss test value and core-loss type designation shall be based upon the highest core loss of all the end tests of the component test lots made in compliance with Sections 13, 14, and 15.

17. Rejection and Rehearing

17.1 Material that fails to conform to the requirements of this specification may be rejected by the user. The rejection shall be reported to the producer promptly and in writing. The rejected material shall be set aside, adequately protected, and correctly identified.

17.2 The producer may make claim for a rehearing. In this event, the user shall make samples which are representative of the rejected material available to the producer for evaluation.

18. Marking and Packaging

18.1 *Marking*—Each package of coils or lift of cut lengths shall have firmly attached to it, outside its wrappings, a tag showing the user's order number, specification number, grade designation, coating or surface type designation, thickness, width (and length if in sheet form), weight, and test lot number. In addition, each wide coil shall have the specification number, grade designation, coating or surface type designation, thickness, width, weight, and test lot number marked on the outer surface of the coil itself. In a package of narrow coils, each narrow coil in the package shall be tagged with the specification number, grade designation, coating or surface type designation, thickness, width, and test lot number.

18.2 *Packaging*—Methods of packaging, loading, and shipping, unless otherwise specified, shall correspond to Practices A 700.

19. Keywords

19.1 electrical steel; grain-oriented; high permeability

APPENDIX

(Nonmandatory Information)

X1. TYPICAL INSULATIVE CHARACTERISTICS AND LAMINATION FACTORS

X1.1 Typical insulative characteristics and lamination factors are given in Table X1.1 and Table X1.2.

TABLE X1.1 Typical Insulative Characteristics, As Sheared

Condition	Surface Type[A]	Surface Insulation Effectiveness[B]
NF	C-2	0.7 A and less
F2	C-5 over C-2	0.6 A and less
F5	C-5 over C-2	0.3 A and less
PQ	C-5	0.85 A and less

[A] See Classification A 976.

[B] Values obtained by Test Method A 717/A 717M at a test pressure of 300 psi (2.1 MPa) at room temperature.

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TABLE X1.2 Typical Lamination Factors

Condition	Surface Type[A]	Lamination Factor, %[B]				
		Aim Thickness = 0.0070 in. (0.18 mm)	Aim Thickness = 0.0090 in. (0.23 mm)	Aim Thickness = 0.0106 in. (0.27 mm)	Aim Thickness = 0.0118 in. (0.30 mm)	Aim Thickness = 0.0138 in. (0.35 mm)
NF	C-2	≥95.0	≥95.5	≥96.0	≥96.0	≥96.0
F2	C-2 over C-2	≥94.5	≥95.0	...	...	...
F5	C-5 over C-2	...	≥94.0	≥94.5	≥95.0	≥95.5
PQ	C-5	...	...	...	≥96.0	≥96.5

[A] See Classification A 976.
[B] Values obtained by Test Method A 719/A 719M at a test pressure of 50 psi (0.35 MPa) at room temperature.

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