NEMA Magnet Wire Thermal Class Ratings and Corresponding Film Insulation Applications Explained

How Are Ratings Formed And Why Does It Matter?

The NEMA Magnet Wire ratings are approved as the American National Standard through an Accredited Canvass of the American National Standards Institute. It is the world's premier standard for general requirements, product specifications and test procedures for the manufacture and packaging of magnet wire.

Essex Furukawa Magnet Wire will explain how the ratings are formulated and why it is important to know what each classification means to help identify the best product for different applications.

Furthermore, Essex Furukawa will explain the material characteristics and applications for different film insulations.

Knowing which type of insulation—from paper to polyimide—can make the difference between peak performance or failure within different applications.

How Thermal Classes are Derived

Per NEMA, the thermal class of magnet wire is based upon:

- Temperature Index
- Heat Shock

Per ASTM, temperature index is a number which permits comparison of the temperature/time characteristics of an electrical insulating material, or simple combination of materials, based on the temperature in degrees Celsius which is obtained by extrapolating the Arrhenius plot of life versus temperature to a specified time, usually 20,000 hours (ASTM D 2307: *Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire)*

Per IEEE, it is an index that allows relative comparisons of the temperature capability of insulating materials or insulation systems based on specified controlled test conditions.

Heat shock is a test that measures the ability of film insulation on magnet wire to resist cracking when exposed to rapid temperature change after being physically stressed. Heat shock capability shall be at least 20°C higher than the class temperature of the wire insulation type.

CLASS	O	A	E	B	F	H	200 (N/K)	220 (R/M)	C	250
TEMPERATURE C	90	105	120	130	155	180	200	220	240+	250 (IEC)

Here are magnet wire insulation thermal classes recognized by NEMA and/or IEC:

These are thermal classes of the magnet wire and are not intended to be the class of the electrical equipment in which the wire is used.

Details on the testing involved to determine thermal class follow.

Temperature Index

Testing performed per ASTM D 2307: Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire.

SUB-COMMITTEE D09.17, Thermal Capabilities

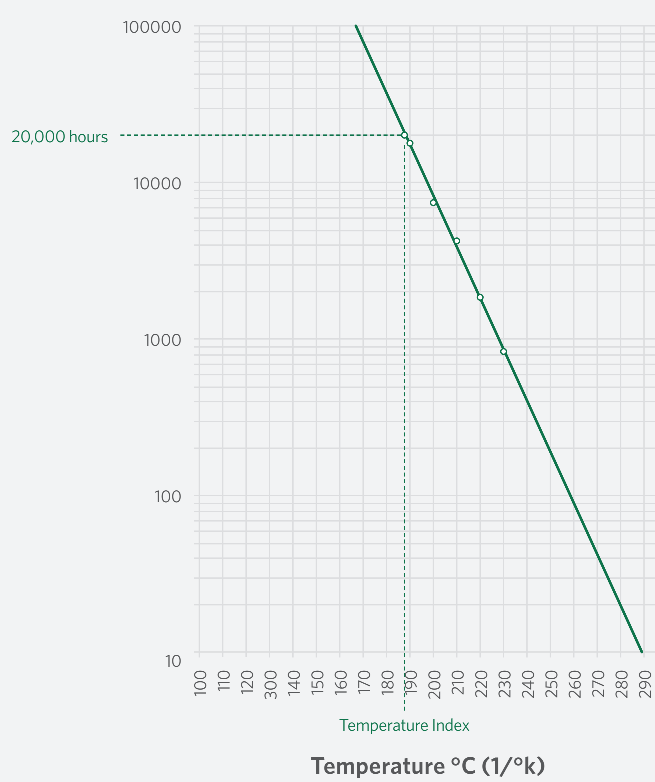
This test method specifies the preparation of specimens, the aging of these specimens at elevated temperatures, and the periodic testing of the specimens by applying a preselected proof voltage.

The cyclic exposure to elevated temperature is repeated until the samples fail the proof test, and the time to failure is calculated. The test is carried out at three or more temperatures and a regression line is calculated and plotted.

Rules

- Must have at least three temperature points plotted
- Minimum of 95% correlation coefficient on data points (line must be pretty straight)
- No data points less than 100 hours are valid
- Must have at least 5,000 hours at 20°C higher than anticipated thermal index rating. For example, for 180°C thermal index there must be at least 5,000 hours at 200°C.

Temperature Index for a Class 180 Insulation



The Temperature Index (or Relative Temperature Index) for a wire insulation is the temperature at the 20,000 hour intercept.

The expected thermal endurance for other temperatures can be determined by finding the intercept for the temperature of interest on the regression line.

Many insulations deteriorate according to the formula:

$$L = Ae^{B/T}$$

Where:

L = Time to failure, in log average hours
T = absolute temperature, in degrees Kelvin
A, **B**= constants for each insulation, and
e = base of natural logarithms.

or expressed as a linear function:

$$\log_{10} L = \log_{10} A + (\log_{10} {}^{e}) \cdot (B/T)$$

let:

Y = $\log_{10}$ L
a = $\log_{10}$ A
X = 1/T
B = $\log_{10}{}^{e} \cdot$ B

Then:

$$Y = a+bX$$

Using the method of least squares, a and b can be calculated from the following:

$$a = (\Sigma Y - b\Sigma X)/N$$

$$b = (N\Sigma XY - \Sigma X\Sigma Y)/(N\Sigma X^2 - (\Sigma X))^2$$

where:

X = 1/T = reciprocal of the test temperature, in degrees Kelvin
N = number of test temperatures used
Y = $\log_{10}$ L = logarithm of the test specimen time to fail (in hours), at each test point.
Σ = summation of N values

Knowing the constant “a” and the slope, “b”, of the regression line, the temperature at any required life can be calculated from:

$$Y = a+bX$$

Heat Shock

Film insulation of magnet wire is stressed during winding and forming operations. It is further stressed by temperature changes in processes of windings, and during normal operation of the apparatus. This test is used to evaluate the resistance to cracking of the film insulation. Some typical test conditions for copper magnet wire are:

AWG	% ELONGATION	MANDREL DIAMETER
4-9	30	N.A.
10-13	25	5d
14-30	20	3d
31-44	20	3d

After stretching the wire and wrapping it around a mandrel, the sample is placed in an oven for 30 minutes, removed and examined for cracks. The oven temperature is set, per the NEMA requirement, for the insulation being tested.

How Thermal Classes are Used

Thermal class requirements dictate the type of magnet wire insulation used.

THERMAL CLASS	INSULATION MATERIAL
90	Paper
105	Paper
105	Polyamide (Nylon)
105	Polyvinyl Acetal, Formvar
120	Polyvinyl Acetal, Formvar
155	Polyurethane
155	Glass, Polyester-glass
180	Polyurethane
180	Polyester (solderable)
200	Polyester (non-solderable)
220	Polyamide-imide
240	Polyimide
260*	Modified Polyimide

** 260 is not an official NEMA Thermal class rating*

Materials can be used as solecoats, or in conjunction with others as basecoats, midcoats and topcoats, to enhance the insulation's overall properties. The thermal class of the final construction may be different than those of the individual materials which comprise it.

While thermal class requirement can determine the candidates, the optimal insulation will be determined by the ability to best meet all the requirements of the application.

Guidelines for choosing the best insulation follow.

Material Characteristics and Applications

Film Insulations

Polyvinyl Acetal

- MW 15-C/A (round), 18-C/A (rectangular, square) wire Formvar

  Thermal Class: 105°C

  - The thermal class for this enamel is only 105°C, but it is resistant to heat shock at 175°C

- MW 86-C/A (round), 87-C/A (rectangular, square) wire Formvar-EXTRA

  Thermal Class: 120°C

  - While the thermal class for this enamel is 120°C, its actual temperature index is well over 130°C
  - Formvar has been in use for many years in many applications. Most of those applications have been converted to other film insulations with higher thermal properties
  - Formvar is very resistant to hot oil, so it is still widely used in oil filled transformers

Polyurethane

- MW 80-C/A Soderon® FS/155
- MW 82-C Soderex®/180
- MW 83-C Soderon®/180

  Thermal Class: 155°C, 180°C

  - Can be soldered without prior removal of the wire insulation
  - Not for high current or high temperature applications, such as locked rotor conditions
  - Nylon (polyamide) overcoat improves heat shock and windability on larger sizes, with some loss in solderability

  Applications Include:

  - Small motors and transformers
  - Relay coils
  - Electronic sensor coils

Solderable Polyester

- MW 77-C Solidex®
- MW 78-C Solidon®

  Thermal Class: 180°C

  - Solderable wire insulation with higher thermal properties than polyurethanes
  - Requires higher temperature to solder than polyurethanes
  - With or without nylon topcoat

  Applications Include:

  - Specialty coils

- Shaded pole motor coils
- Electronic coils

Polyester/Nylon

- MW 76-C/A wire Nytherm®

  Thermal Class: 180°C

  - Motor applications, except hermetic motors containing refrigerants
  - Motor armatures where the wire is hot staked to the commutator tangs
  - Applications where wire insulation is removed by flame or insulation piercing terminations are used
  - Not good for high moisture applications

  Applications Include:

  - Fractional and integral horsepower motors
  - Coils and relays
  - Control and dry type transformers
  - Encapsulated coils
  - DC Field coils

Polyester/Polyamide-Imide

- MW 35 and 73-C/A (round), MW 36-C/A (rectangular, square) wire GP/MR-200®
- Version for inverter duty motors (no separate NEMA designation) – UltraShield ® Plus

  Thermal Class: 200°C (copper), 220°C (aluminum)

  - Modified polyester basecoat with amide-imide topcoat, with superior toughness and resistance to chemicals and moisture
  - Higher thermal properties than polyester or polyester/nylon:
    - Temperature Index
    - Heat shock
    - Thermoplastic flow
    - Burnout (AC overload)
    - Standard for motor repair shops

  Applications Include:

  - Open motors
  - Hermetic motors subjected to refrigerants
  - Higher moisture applications
  - Motors, generators, transformers and coils requiring improved properties for physical, thermal, and chemical properties

- MW 37-C (round), MW 38-C (rectangular, square) wire GP/MR-EXTRA®

  Thermal Class: 220°C

  - Higher percentage of amide-imide topcoat than MW 35/36/73 provides higher thermal properties, as well as additional toughness and resistance to chemicals and moisture

Polyamide-Imide

- MW 81-C (round), MW 84-C (rectangular, square) wire Amide-Imide

  Thermal Class: 220°C

  - Amide-imide sole coat for superior thermal properties, and maximum toughness and resistance to chemicals and moisture

Polyimide

- MW 16-C (round), MW 20-C (rectangular, square) wire Allex®

  Thermal Class: 240°C

  - Polyimide film is very resistant to high temperatures, and is the product of choice where the magnet wire may be subjected to continuously high operating temperatures or subject to intermittent severe overloads

  Applications Include:

  - Traction motors
  - Industrial motors
  - Fuel system components
  - Fractional and integral horsepower motors
  - High temperature continuous duty coils and relays
  - Hermetic and sealed units
  - Heavy duty hand tool motors
  - Encapsulated coils

Polyimide/Polyamide-Imide

- EnduroTemp™ 260+

  Thermal Class: Exceeds 240°C

  - Polyimide/Polyamide-Imide film that is very resistant to high temperatures, and partial discharge reduction, which will extend the life of traction motors in critical transportation applications and has been specifically designed to withstand higher operating temperatures exceeding 260°C thermal endurance

  Applications Include:

  - Traction motors
  - Down hole pump motors
  - Industrial motors
  - Heavy mining equipment
  - Fractional and integral horsepower motors
  - High Temperature continuous duty coils and relays
  - Hermetic and sealed units
  - Encapsulated coils

Bondables

Polyurethane/Nylon

- MW 136-C Soderbond® N/155

  Thermal Class: 155°C

Polyester/Polyamide-Imide

- MW 102-C/A Polybondex® G

  Thermal Class: 180°C

Other bondables with no NEMA designation are also available

Bondable magnet wires consist of basecoat enamels overcoated with a bondcoat or "cement coat". The usual general intent for using a bondcoat product is to eliminate the need for varnishing. After the coils are wound, heat is applied and the bondcoat melts. This holds the coils together while the device is in service. Some bondcoats can also be activated with a solvent.

For energy efficient devices, bondable products take up more space, reducing efficiency. The bondcoat build must be thick enough to effect adhesion between wires, which reduces the amount of base insulation available.

Applications Include:

- Toroidal and helical coils
- Solenoid and voice coils
- Clutch and brake coils
- Motor field coils

Wrapped Insulation

Paper

- MW 31-C/A (round), MW 33-C/A (rectangular, square)

  Thermal Class: 90°C, 105°C

  - Currently, the main use for paper covered wire is oil filled transformers. The combination of the paper and oil give the insulation exceptional resistance to impulse and AC dielectric. The paper consists of rope or kraft fibers, or a combination of them. The paper can be treated to thermally upgrade the insulation. The papers are wrapped helically around the wire in one or more layers.

Glass and Glass/Polyester:

- MW 41-C through MW 55-C

  Thermal Class: 155°C, 180°C, 200°C

  - Glass and polyester/glass insulations are served filaments wound around the magnet wire, which can be film coated or bare wire; rectangular, square, or round. The glass fibers provide high temperature characteristics, while the fused polyester fibers provide abrasion resistance and flexibility. The fibers can be overcoated with a varnish, such as epoxy, polyester, or silicone. The fibrous overcoating also aids the overall insulation by absorbing varnish in subsequent processing operations.

Applications Include:

- Form wound coils for motors and generators
- Heavy duty service DC field coils
- Random wound severe duty motors
- Hydro power generators

Aromatic Polyamide Paper:

- MW 60-C/A (rectangular, square)
- MW 61-C/A (round)

Thermal Class: 220°C

- Polyamide paper combines chemical and moisture resistance with high temperature capability

Applications Include:

- Dry type and oil filled transformers.
- Lifting magnets
- Form wound coils

Aromatic Polyimide Tape:

- MW 64-C/A (rectangular, square)
- MW 65-C/A (round)

Thermal Class: 240°C

Polyimide fused tape, coated with Fluorinated Ethylene Polymer (FEP), on one or both sides to provide adhesion, moisture resistance, and a smooth surface. It is very resistant to solvent attack and provides excellent high temperature stability.

Applications Include:

- Submersible oil well pump motors
- Traction motors
- Alternator/motor off-highway construction units
- Rolling mill motors
- Lift truck motors