

# **NEMA Magnet Wire Thermal Class Ratings**

How to Use Them, and How They are  
Derived

Ron Beeckman – Essex Group, Inc.

## **Thermal Class of Magnet Wire is Based upon:**

### **Temperature Index:**

(ASTM): 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.*

(IEEE): An index that allows relative comparisons of the temperature capability of insulating materials or insulation systems based on specified controlled test conditions.

### **Heat Shock:**

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.

## Thermal Classes

<u>Class</u>	<u>Temperature°C</u>
O	90
A	105
E	120 (IEC)
B	130
F	155
H	180
200 (K)	200
220 (M)	220
C	240+
250	250 (IEC)

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

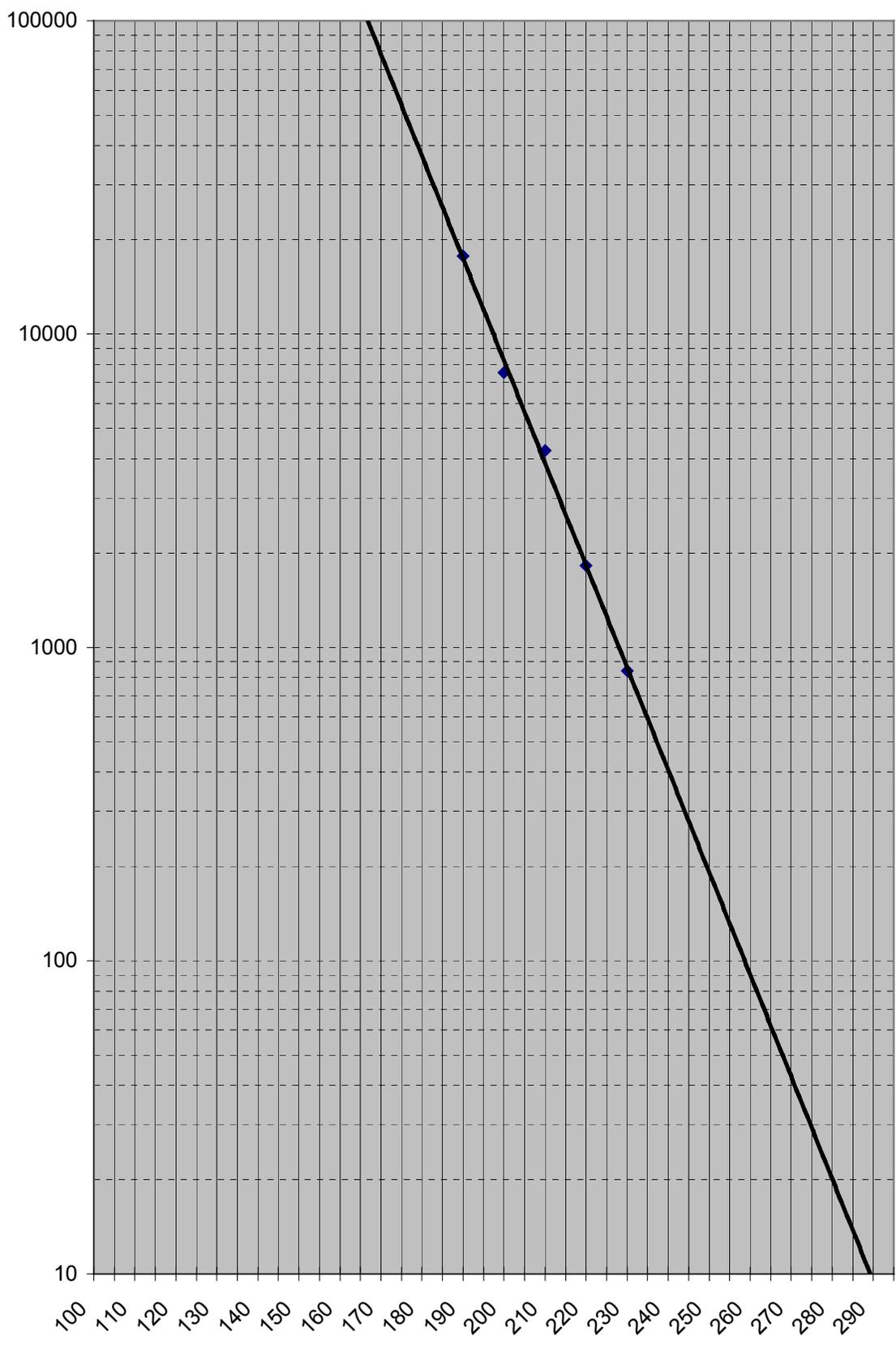
**ASTM D 2307**: Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire.

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.

The temperature index of the wire insulation is the point where the extrapolation of the thermal life plot of the data crosses the 20,000 hour point.



## **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 a minimum of one end point that is at least 5,000 log average hours of life, and that is at least 20°C above the Thermal Index for the insulation

Example: For a Class 180° (H) wire insulation, 5,000 hours minimum at 200°C would be OK.

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

For lower temperatures, follow the insulation life line to determine the expected log average hours of expected life.

Many insulations deteriorate according to the formula:

$$L = A e^{B/T}$$

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:

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

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

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.

$\sum$  = 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:

<u>AWG</u>	<u>% Elongation</u>	<u>Mandrel Diameter</u>
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 ½ hour, removed and examined for cracks.

<b><u>Thermal Class</u></b>	<b><u>Insulation Types</u></b>
90	Paper
105	Paper, cotton
105 Solderable	Polyurethane
105	Nylon
105	Polyvinyl Acetal, Formvar
130	Epoxy
130 Solderable	Polyurethane
155	Polyester
155 Solderable	Polyurethane
155	Glass
180	Polyester
180 Solderable	Polyurethane
180 Solderable	Polyester-imide
200	Polyester/amide imide, AI
220	Amide-Imide
240	Polyimide

## **Material Characteristics and Applications**

### **“Polyurethane”**

- Can be soldered wire to wire and to terminals without prior removal of the wire insulation.
- Not for high current or high temperature applications, such as locked rotor conditions.
- Can be overcoated with nylon (polyamide) to improve heat shock and windability on larger sizes, with some loss in solderability.
- Typical uses include small motors and transformers, relay coils, and electronic sensor coils.
- Availability: typical sizes from 9-44 AWG, in Thermal Class 130°, and from 25-50 AWG for Class 155° and 25-46 AWG for Class 180° C, with or without nylon topcoat. MW 28, 75, 79 and 80. NEMA designation for Class 180 to be determined.

## Solderable Polyester-Imide MW 26, 27, 77 and 78-C

Thermal Class: 155°C and 180°C

With or without nylon topcoat

- Solderable wire insulation with higher thermal properties than polyurethanes.
- Requires higher temperature to solder than polyurethanes.

Uses:

- Specialty coils
- Shaded pole motor coils
- Electronic coils

## Polyester

MW 30-C (180°)

MW 74-C (200°)

MW 74-A (220°C)

4-56 AWG Round wire

- Modified for higher temperature applications than polyurethanes and solderable polyester-imides.
- Not solderable

Typical uses:

- Small appliance and tool motors
- Continuous operation coils
- Sub-fractional, instrument, and servo motors

Polyester/Nylon MW 24 C/A (Class 155°), 76 C/A (Class 180°)

Typical uses include:

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

Suitable for many motor applications, except for hermetic motors containing refrigerants, such as freon R22.

Good for motor armatures where the wire is hot staked to the commutator tangs.

Also good where wire insulation is removed by flame or where insulation piercing terminations are used.

Not especially good for high moisture applications.

Polyester/Amide-Imide MW 35 and 73-C/A, Class 200°C and 220°C, 4-44 AWG Round wire and MW 36-C for rectangular and square wire

Modified polyester basecoat with amide-imide topcoat, with superior toughness and resistance to chemicals and moisture.

Higher thermal properties than polyester or polyester/nylon; Thermal Index, heat shock, thermoplastic flow, burnout (AC overload)

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

Also available in versions for inverter duty motors – no separate NEMA designation for this product.

## Bondables

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. Some uses of bondable magnet wires include:

- Television deflection yoke coils
- Toroidal and helical coils
- Solenoid and voice coils
- Clutch and brake coils
- Motor field coils

## Polyvinyl Acetal (Formvar)

MW 15 C/A 4-50 AWG Round and 18 C/A  
Rectangular and Square

Formvar has been in use for many years. It is a tough enamel and has been used in many applications. Most of the applications have been converted to other film insulations with higher thermal properties.

While the thermal class for this enamel is only 105°C, it is resistant to heat shock at 175°C.

Formvar is very resistant to hot oil, which makes it particularly suitable for use in oil filled transformers.

## Polyimide Film

MW 16-C 4-50 AWG Round, 71-C Round wire 14-30 AWG for hermetic use, and 20-C, Rectangular and Square Wire, Class 220°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.

Some typical uses include:

- Fractional and integral horsepower motors
- High temperature continuous duty coils and relays
- Hermetic and sealed units
- Heavy duty hand tool motors
- Encapsulated coils

## Paper: MW 31 & 33-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.

## Aromatic Polyamide Paper:

NEMA MW 60-C/A (Square and Rectangular)

NEMA 61-C/A (Round wire)

Thermal Class: 220°C

Nomex<sup>®\*</sup> polyamide paper combines chemical and moisture resistance with high temperature capability.

Some uses include:

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

\* Registered trademark of E.I. du Pont de Nemours & Co., Inc.

## Aromatic Polyimide Tape:

NEMA MW 62-C (Rectangular and Square)

NEMA MW 63-C (Round, AWG's 1-14)

Thermal Class 220°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.

Uses include:

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

## Glass and Glass/Polyester covered:

NEMA MW 41-C through MW 48-C

NEMA MW 50-C through MW 53-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.

Some applications for glass and glass/polyester insulated wire include:

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

- Hydro power generators