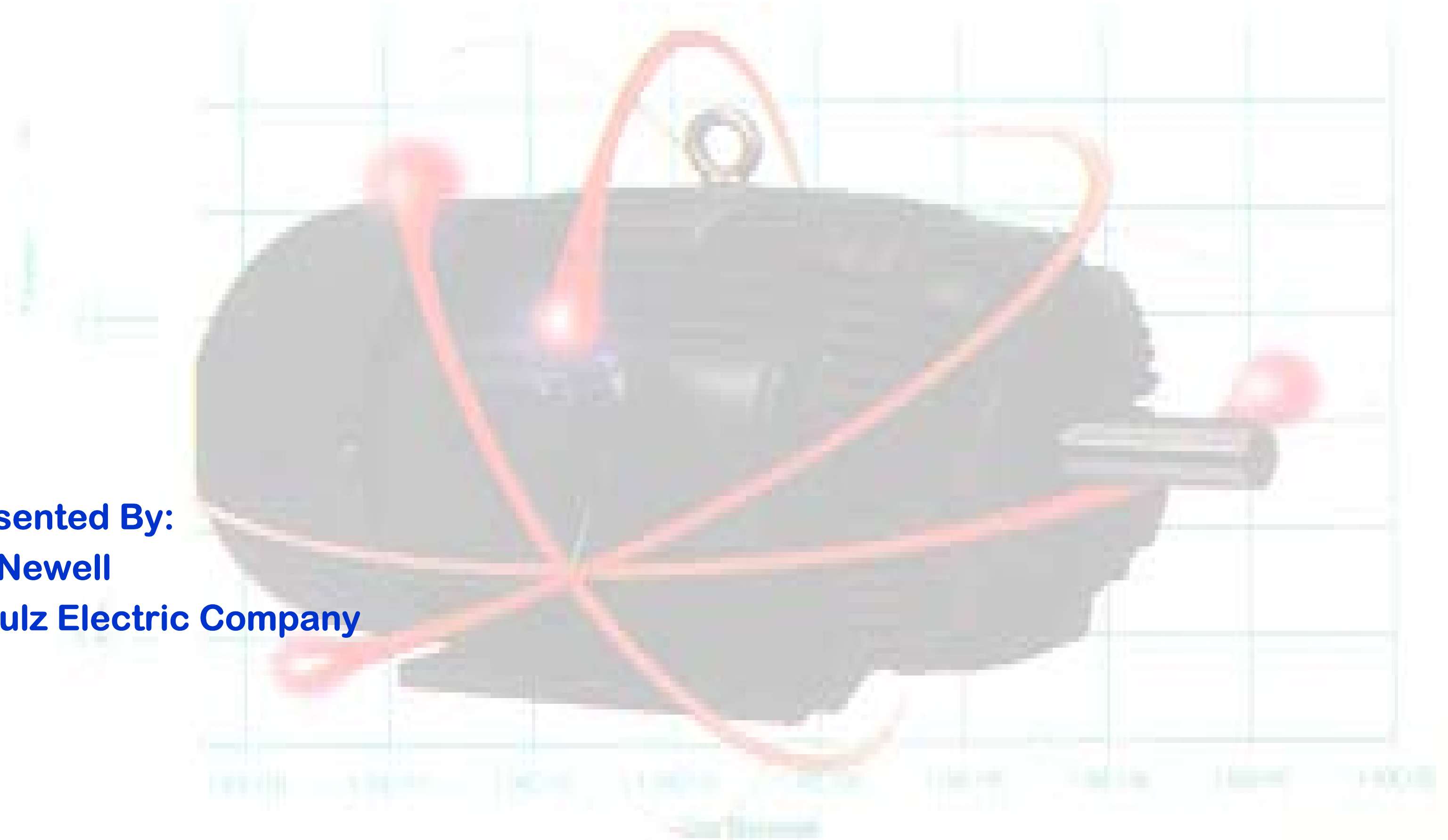
Motor Ratings and Qualified Life Issues



Presented By:
Bill Newell
Schulz Electric Company

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Motor Ratings

Motor Ratings Include:

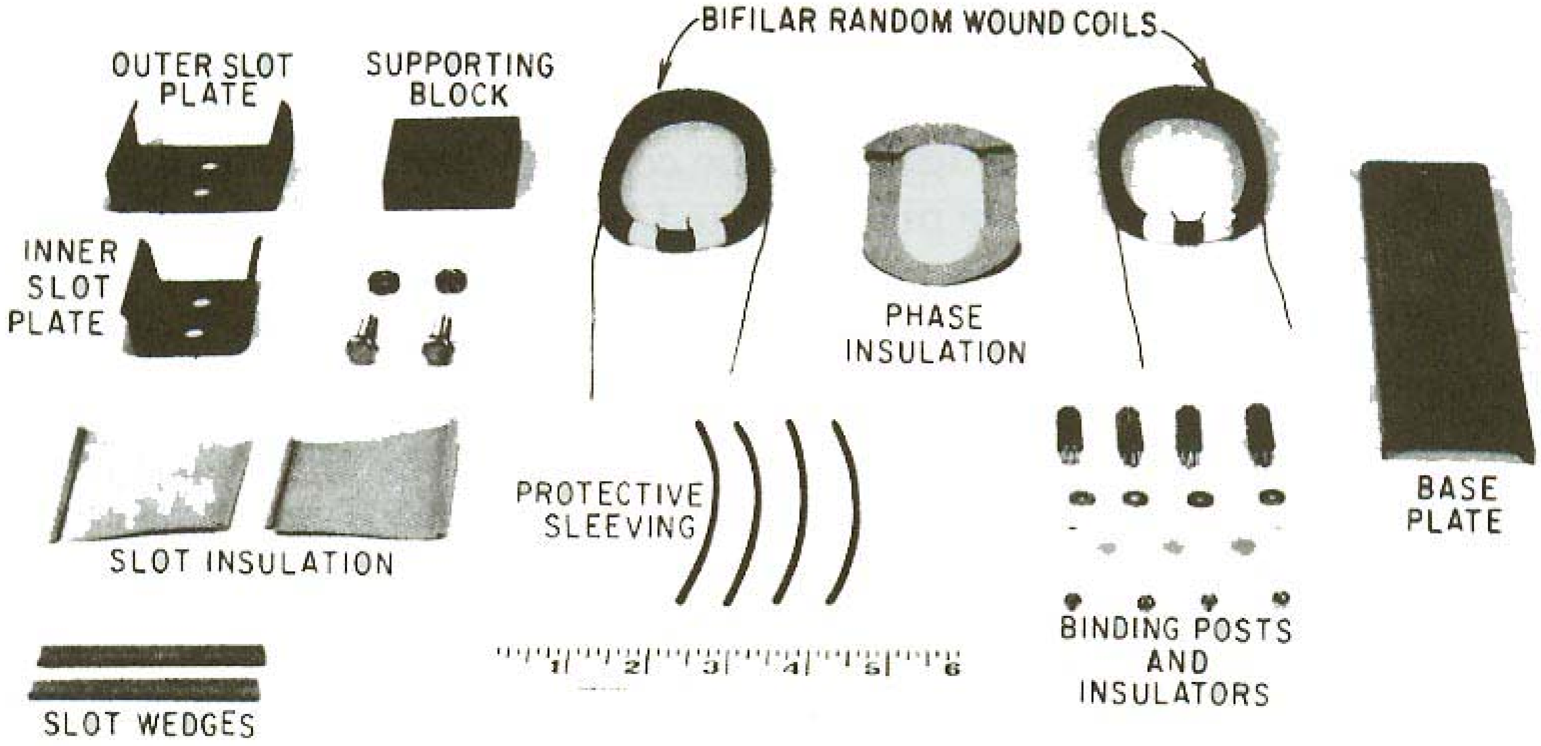
- Voltage
- Speed
- KVA Code
- Full Load Current
- Frame
- Design
- Allowable Ambient Temperature or Full Load Temperature Rise
- Insulation Class

Temperature Rise v. Insulation Class

Motor temperature rise and motor insulation class are two different things

- ➲ The temperature rise of the motor is dependent on the winding design and the motor's ability to remove heat
- ➲ The insulation class is the thermal capability of the insulation system
- ➲ The insulation class of a motor's insulation system can be changed to a higher (or lower) class without affecting the temperature rise of the motor

Establishing Thermal Class



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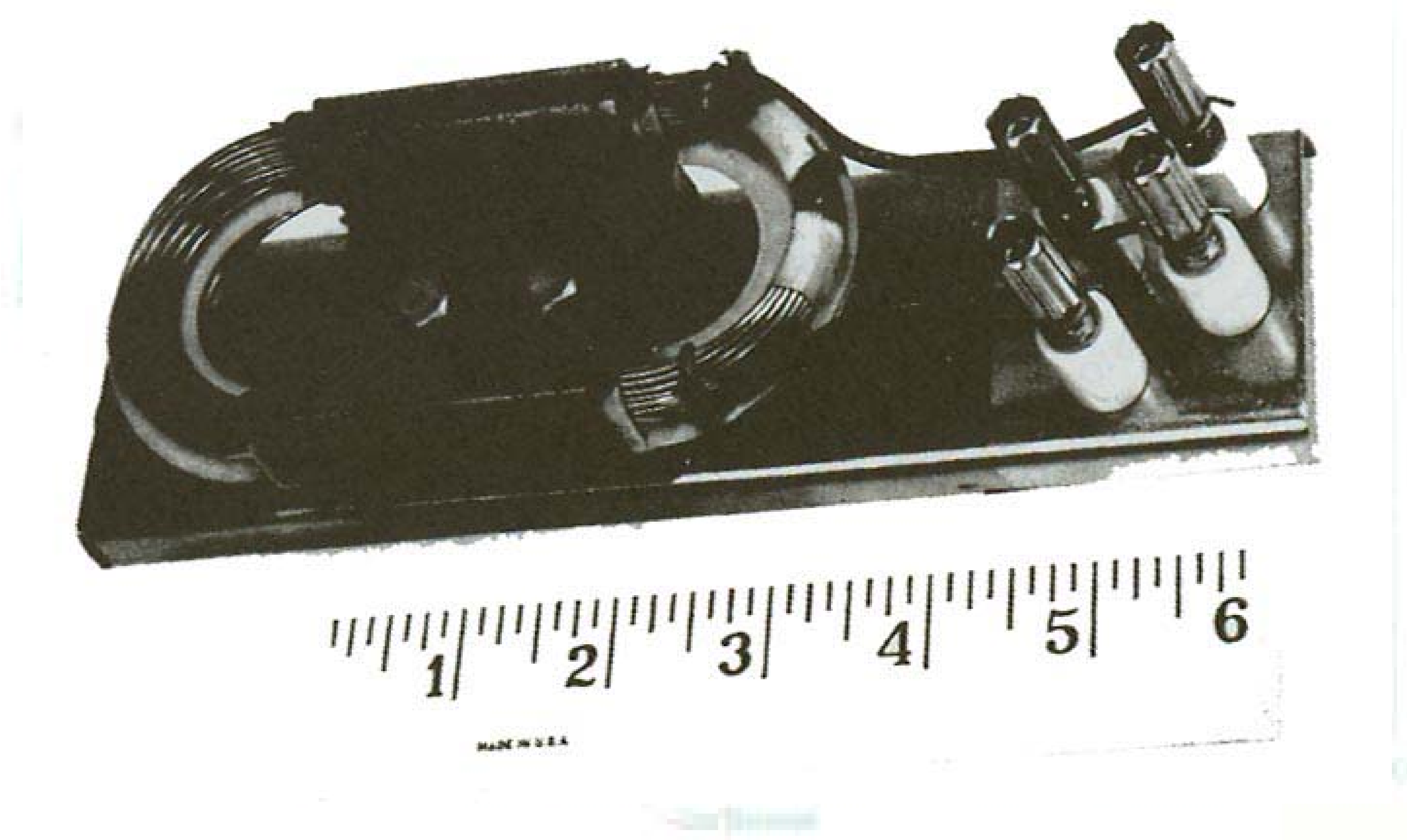
Establishing Thermal Class



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Testing Motorettes and Formettes

Codes and Standards

- IEEE-117 for Random-Wound Systems
- IEEE-275 for Form-Wound Systems
- UL 1446 - General Insulation Systems, can be random, form, motors, solenoids, coils, etc.

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Testing Motorettes and Formettes

- Test 3 sets of samples with 10 samples per set
- Test at three separate temperatures at least 20 C apart
- Perform thermal aging, mechanical aging, moisture exposure, voltage testing
- Test until all samples fail
- Graph failures to determine activation energy and develop the Arrhenius curve

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Data From IEEE 117 Testing

Batch 1 Data			Batch 2 Data			Batch 3 Data		
Motorette	Temp °C	Life (hrs)	Motorette	Temp °C	Life (hrs)	Motorette	Temp °C	Life (hrs)
B1M1	210	2520.17	B2M1	230	1009.08	B3M1	250	264
B1M2	210	2520.17	B2M2	230	721.08	B3M2	250	311.75
B1M3	210	2856.17	B2M3	230	721.08	B3M3	250	311.75
B1M4	210	2520.17	B2M4	230	913.08	B3M4	250	311.75
B1M5	210	2184.17	B2M5	230	1009.08	B3M5	250	311.75
B1M6	210	2184.17	B2M6	230	913.08	B3M6	250	311.75
B1M7	210	2520.17	B2M7	230	913.08	B3M7	250	311.75
B1M8	210	1848.17	B2M8	230	913.08	B3M8	250	311.75
B1M9	210	2856.17	B2M9	230	1105.08	B3M9	250	311.75
B1M10	210	2520.17	B2M10	230	721.08	B3M10	250	311.75

Table 6-1 Temperature Vs. Life data of motorette samples (Schulz Electric Company).

Log Life Graph of Data

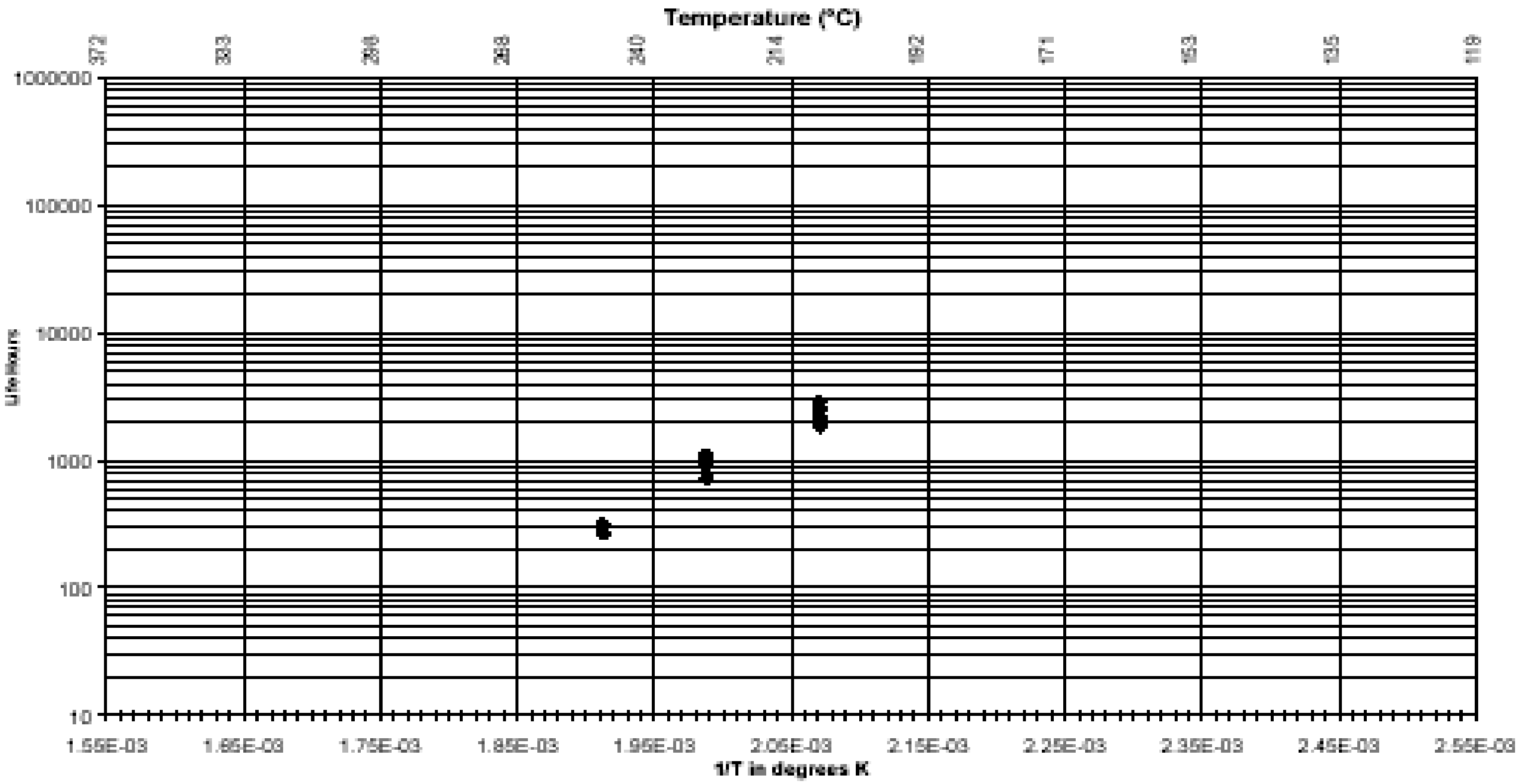

Figure 6-6 log(life in hours) Vs. 1/T (°K) graph of raw data (Schulz Electric Company).

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Least Squares Average of Data

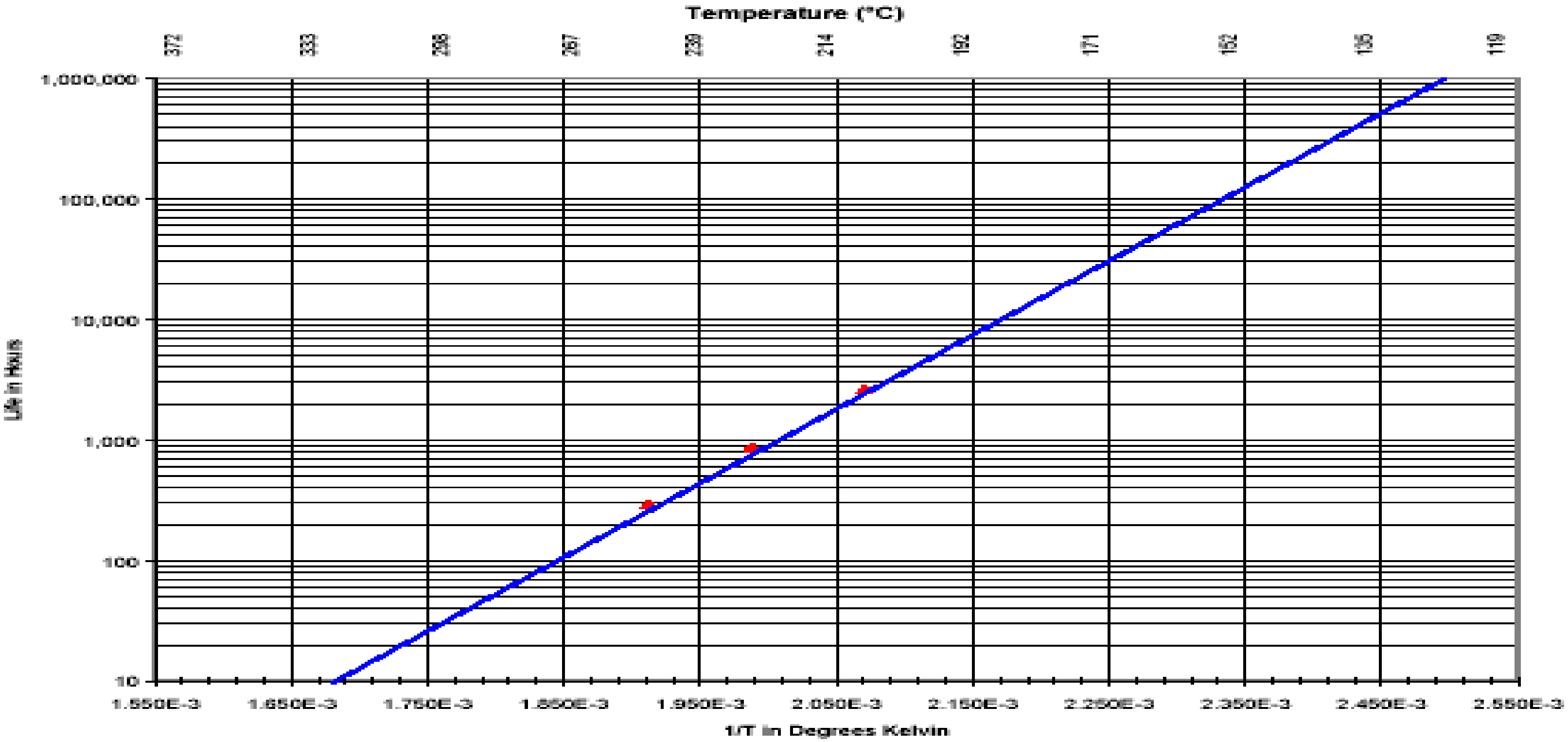
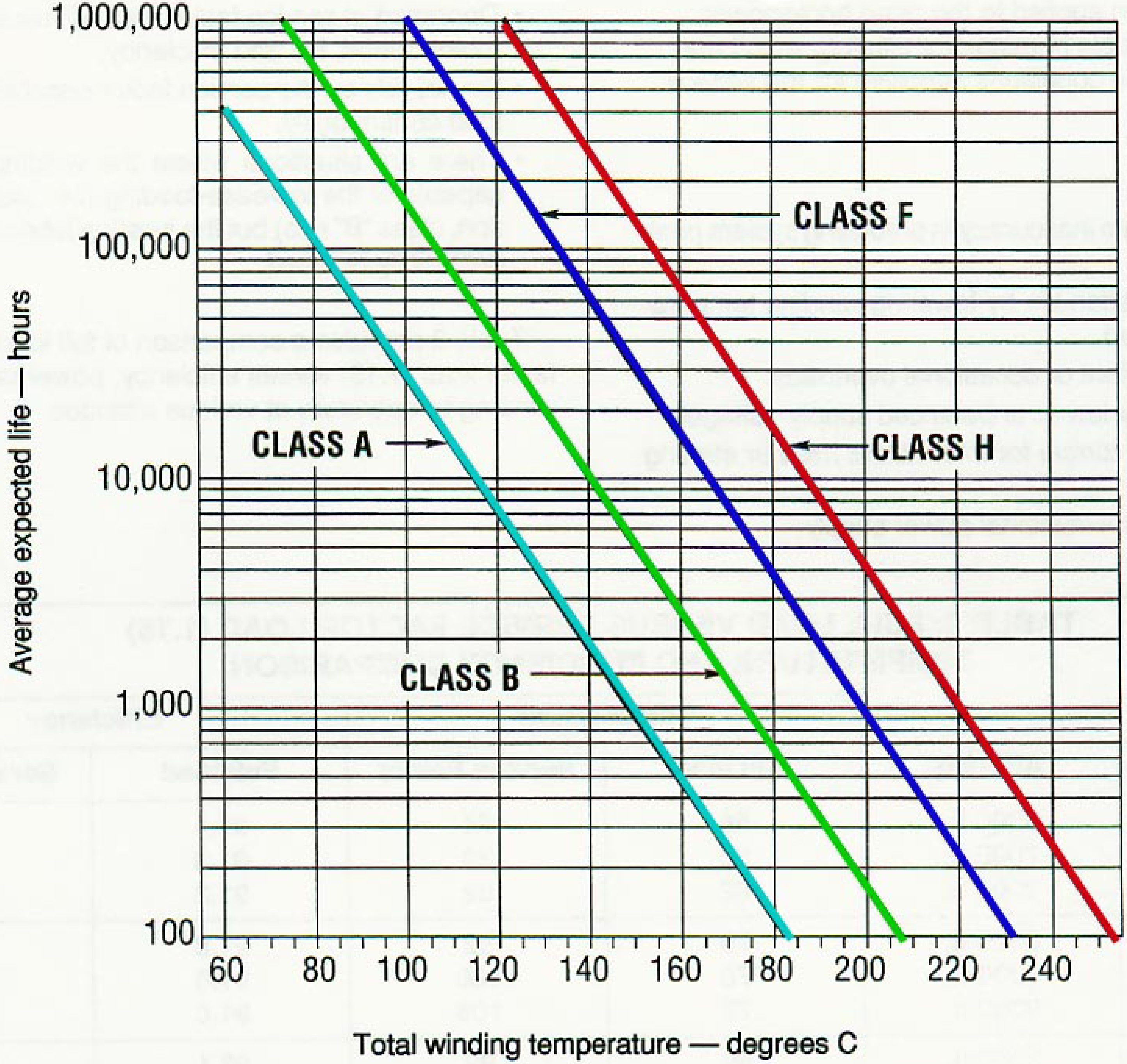


Figure 6-7 "Least Squares" average of the points described by the graph of Figure 6-5.


1,000,000
100,000
10,000
1,000
100
Average expected life — hours
60
80
100
120
140
160
180
200
220
240
Total winding temperature — degrees C
CLASS A
CLASS B
CLASS F
CLASS H

Insulation Classifications

- **Class A - 105 C**
- **Class B - 130 C**
- **Class F - 155 C**
- **Class H - 180 C**

The temperature is the maximum hotspot temperature at which the insulation system can be operated for normal expected service life.

Ambient Temperature and Temperature Rise

Class of insulation (NEMA MG 1-1998, 1.66)	A	B	F	H
Time rating (shall be continuous or any short-time rating given in MG 1-1998, 10.36)				
Temperature rise (based on maximum ambient temperature of 40° C)				
1. Windings by resistance method:				
a. Motors with 1.0 service factor other than those given in items 1c and 1d.	60	80	105	125
b. All motors with 1.15 or higher service factor.	70	90	115	—
c. Totally-enclosed non-ventilated motors with a 1.0 service factor.	65	85	110	135
d. Motors with encapsulated windings and with a 1.0 service factor, all enclosures.	65	85	110	—
2. The temperatures attained by cores, squirrel-cage windings, commutators, collector rings and miscellaneous parts (such as brush holders, brushes, pole tips, uninsulated shading coils, etc.) shall not injure the insulation or the machine in any respect.				

Total Winding Temperature

40 C – Ambient

55 C – Class A
80 C – Class B
105 C – Class F
130 C – Class H

Winding Temperature Rise

10 C – Hot Spot

Thumbrule: A temperature increase of 10 C will reduce the lifetime of the insulation system by one-half.

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Qualified Life as a Function of Temperature

Variables needed to determine insulation life:

E_A = activation energy (eV)
K_B = Boltzman's constant
T_1 = accelerated aging temperature 1 (°K)
T_2 = accelerated aging temperature 2 (°K)
t_1 = accelerated aging at temperature T_1 (hours)
t_2 = accelerated aging at temperature T_2 (hours)

Qualified Life as a Function of Temperature

Before Refurbishment temperature rise = 30 C Ambient + 55 C Winding Rise + 10 C Hot Spot
= 95 C

$$t_1 = [t_2]\left[e^{\left(\frac{E_A}{K_B}\right)\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}\right]$$

$$t_1 = [20{,}0\,00]\left| e^{\left(\frac{0.80}{8.617x10^{-5}}\right)\left(\frac{1}{368}-\frac{1}{413}\right)} \right|$$

t_1 = 312,488 Hours, 35.6 Years

Where:
- E_A = 0.80 eV
- K_B = 8.617 x 10^{-5} eV/°K
- T_1 = 95° C + 273 = 368° K
- T_2 = 140° C + 273 = 413° K
- t_1 = Time at 95° C (hours)
- t_2 = 20,000 hours

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Qualified Life as a Function of Temperature

After Refurbishment temperature rise = 30 C Ambient + 45 C Winding Rise + 10 C Hot Spot
= 85 C

$$t_1 = [t_2]\left[e^{\left(\frac{E_A}{K_B}\right)\left(\frac{1}{T_1}-\frac{1}{T_2}\right)} \right]$$

$$t_1 = [20{,}0\,00]\left[e^{\left(\frac{0.80}{8.617x10^{-5}}\right)\left(\frac{1}{358}-\frac{1}{413}\right)} \right]$$

Where:
E_A = 0.80 eV
K_B = 8.617 x 10^{-5} eV/°K
T_1 = 85° C + 273 = 358° K
T_2 = 140° C + 273 = 413° K
t_1 = Time at 85° C (hours)
t_2 = 20,000 hours

t_1 = 632,237 Hours, 72.2 Years

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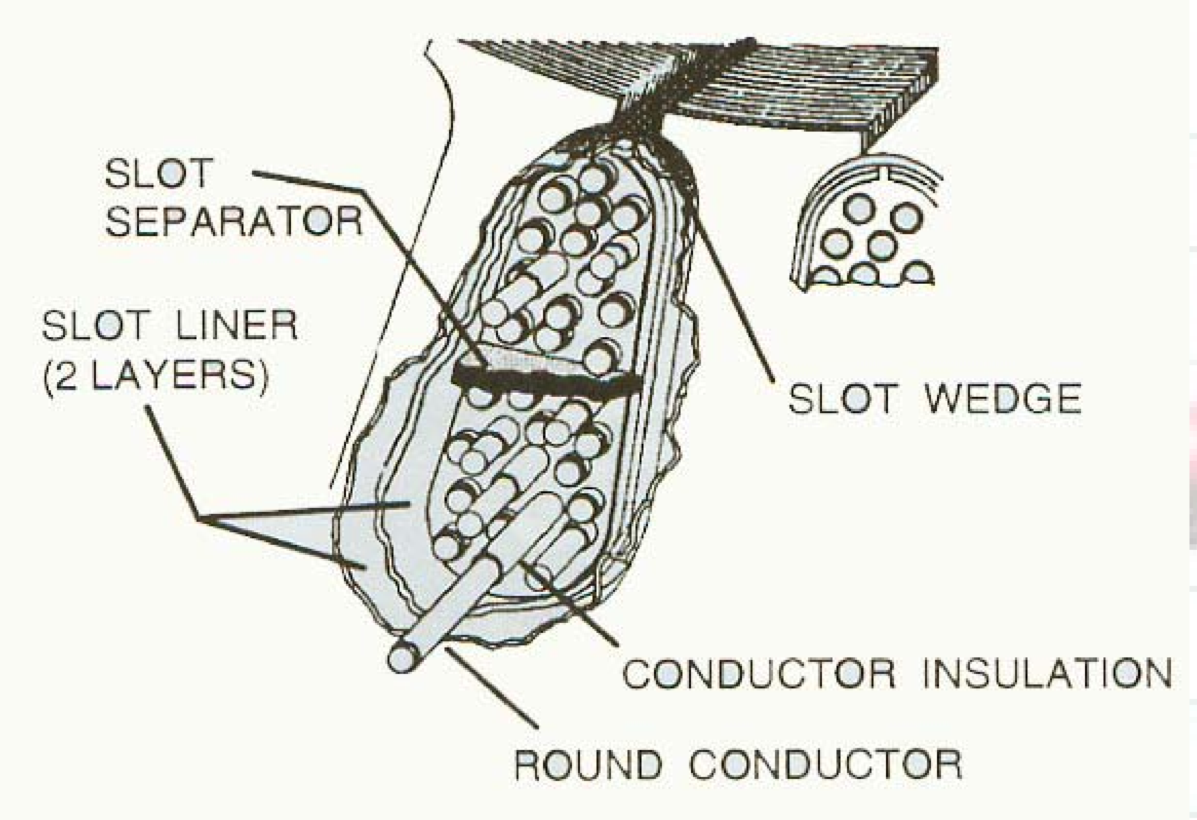
Random-Wound Insulation System



Random-Wound Insulation System

- Slot liner: Nomex-Mylar-Nomex
- Slot wedge: Nomex 410
- Phase separator: Nomex 410
- Phase paper: Nomex 411
- Magnet Wire: Enamel Coated (MW 36C, MW 15C)
- Fiberglass Support Tape
- Silicone Lead Wire
- 15% Silver Solder

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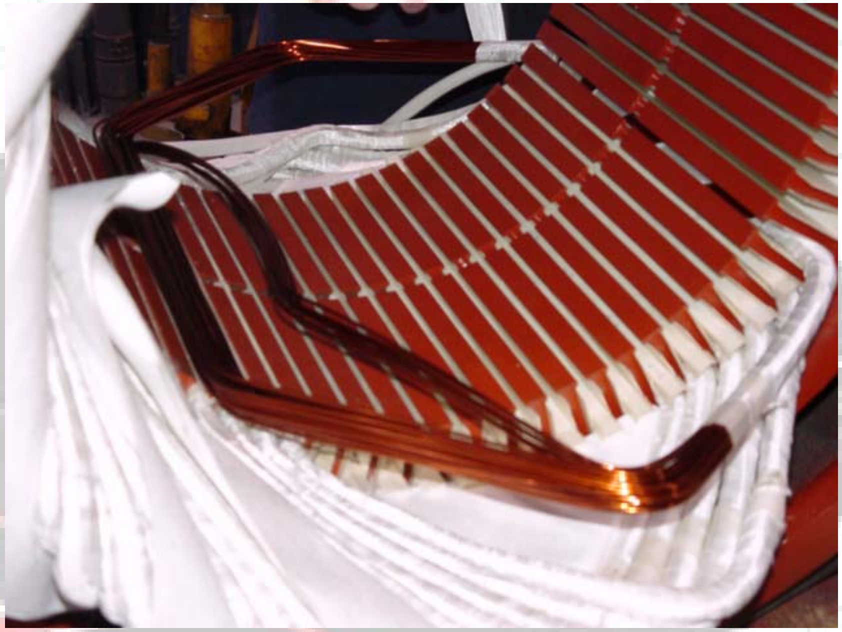
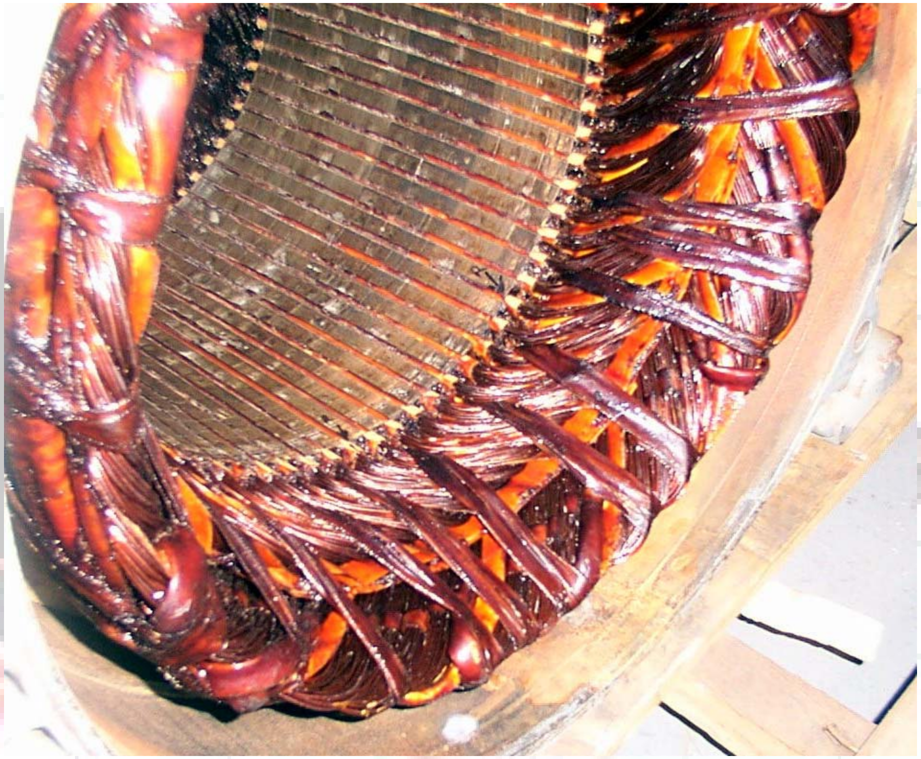
Random-Wound Insulation System



Random-Wound System
(before)



Random-Wound System (before)

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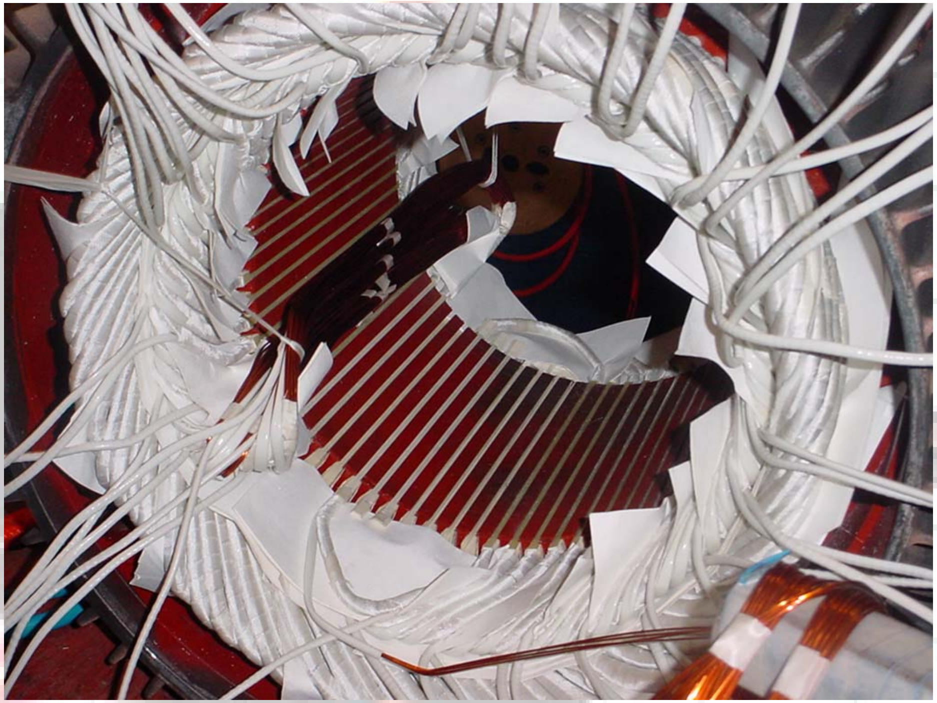
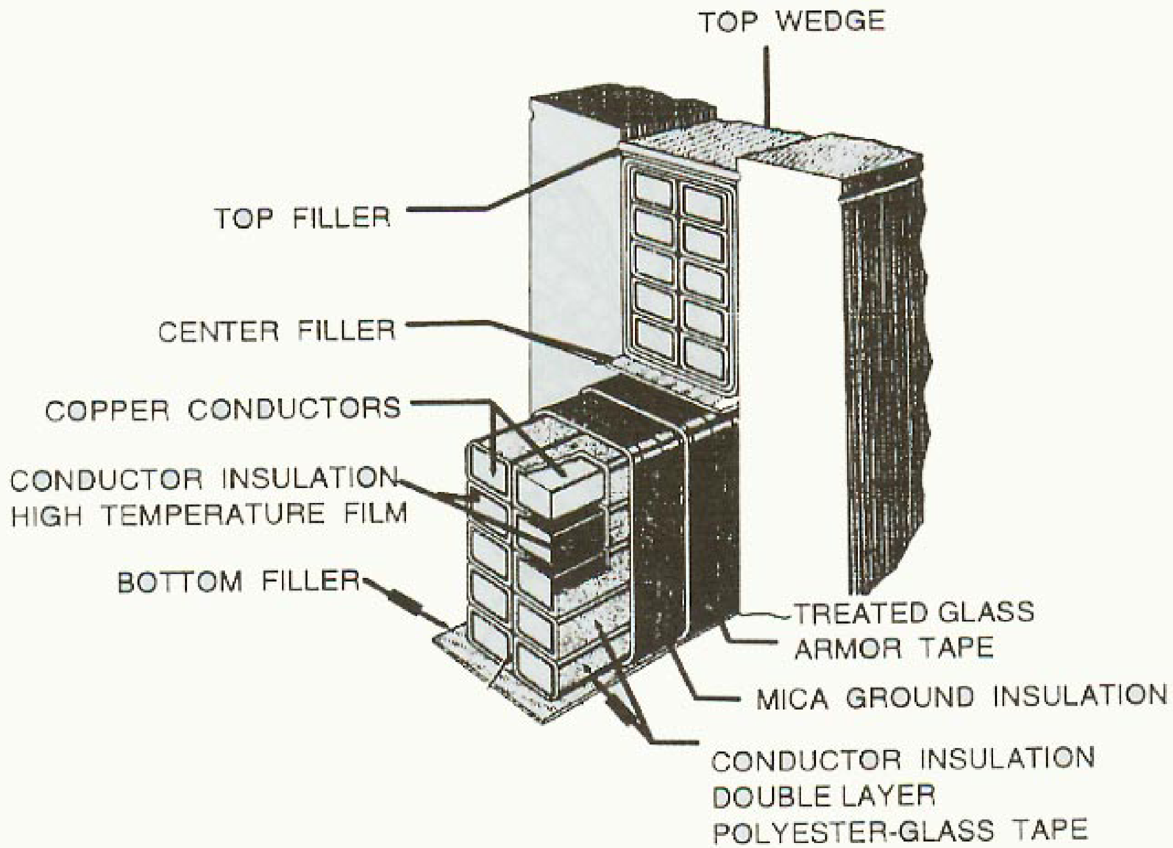
Random-Wound System



Random-Wound Post VPI

Form-Wound Insulation System



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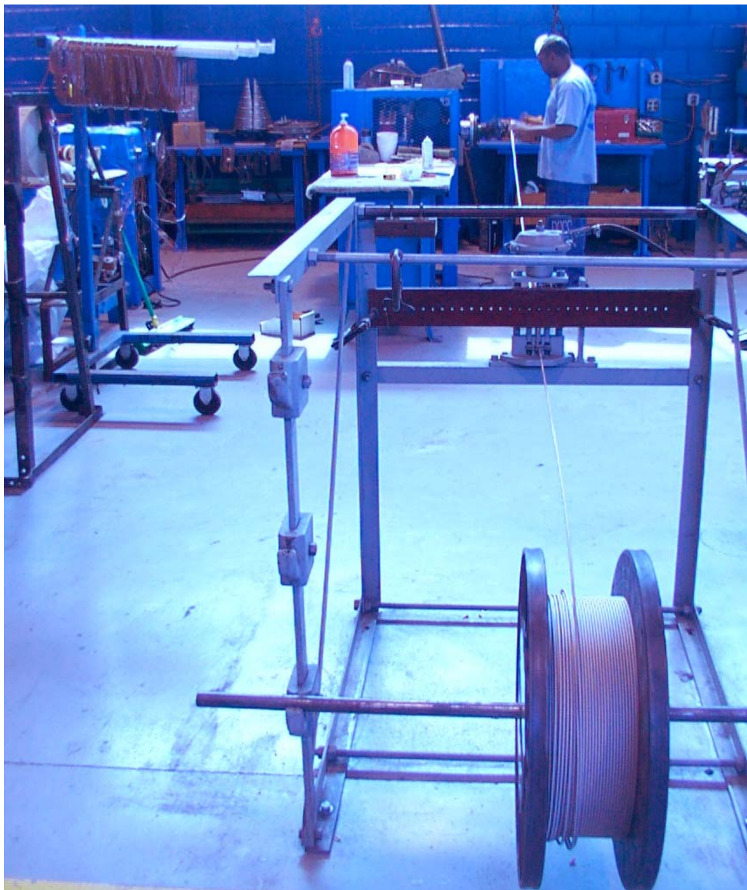
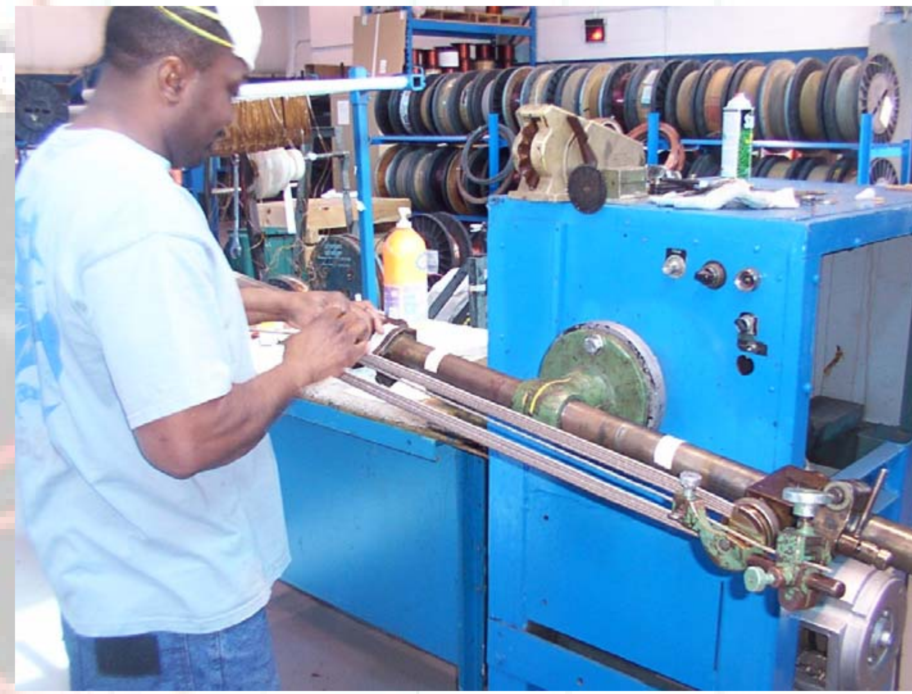
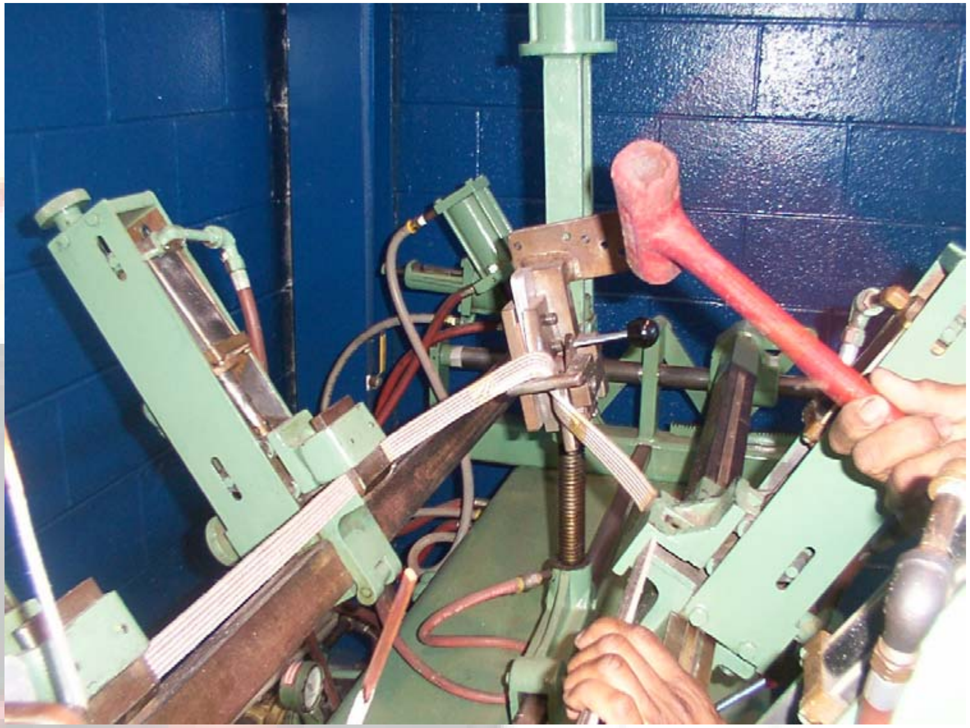
Form-Wound Insulation System

- Slot wedge: Nomex 410
- Filler Strips: Nomex 410
- Slot Wedge: G-200
- 15% Silver Solder
- Felt Blocking
- Magnet Wire: Square or Rectangular with Enamel Coating, with or without Fiberglass Coating
- Mica Insulating Tape
- Fiberglass Support Tape
- 7.5 KV EPDM Lead Wire

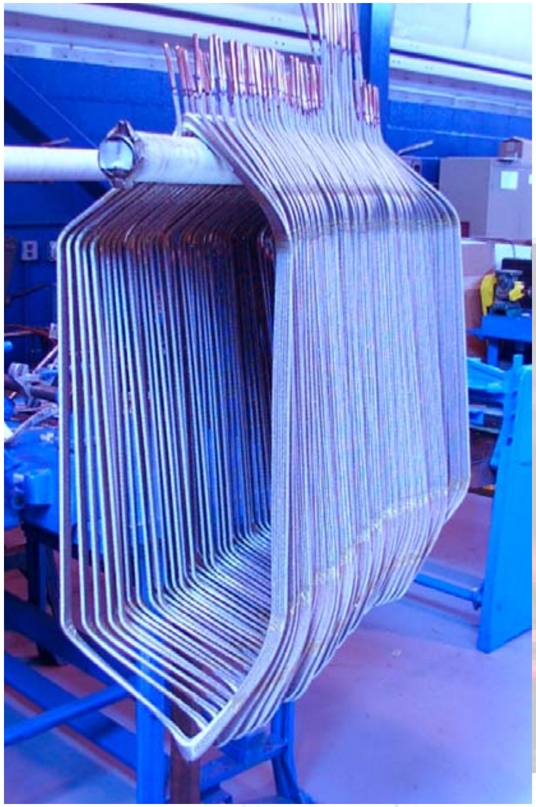
Form-Wound Insulation System

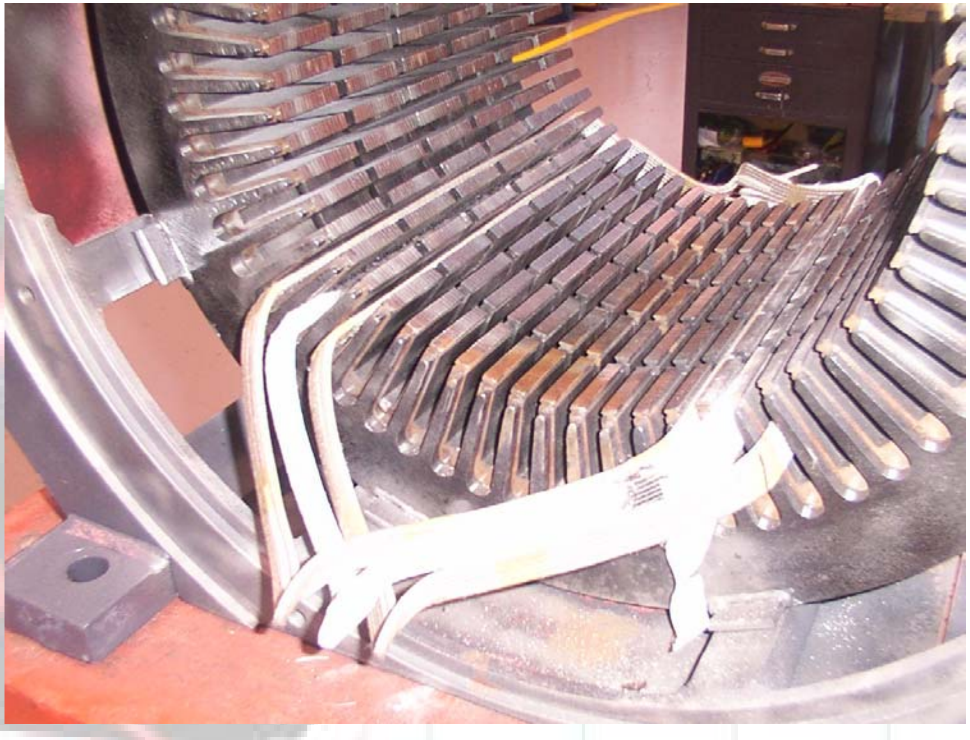




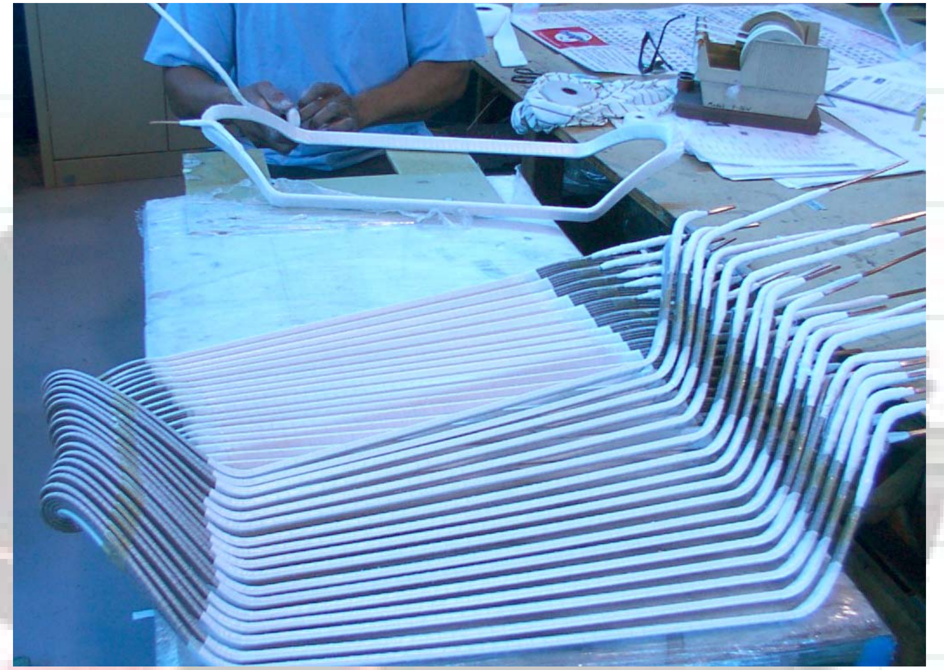


Trial-Fitting of Coils





Adding Mica Tape



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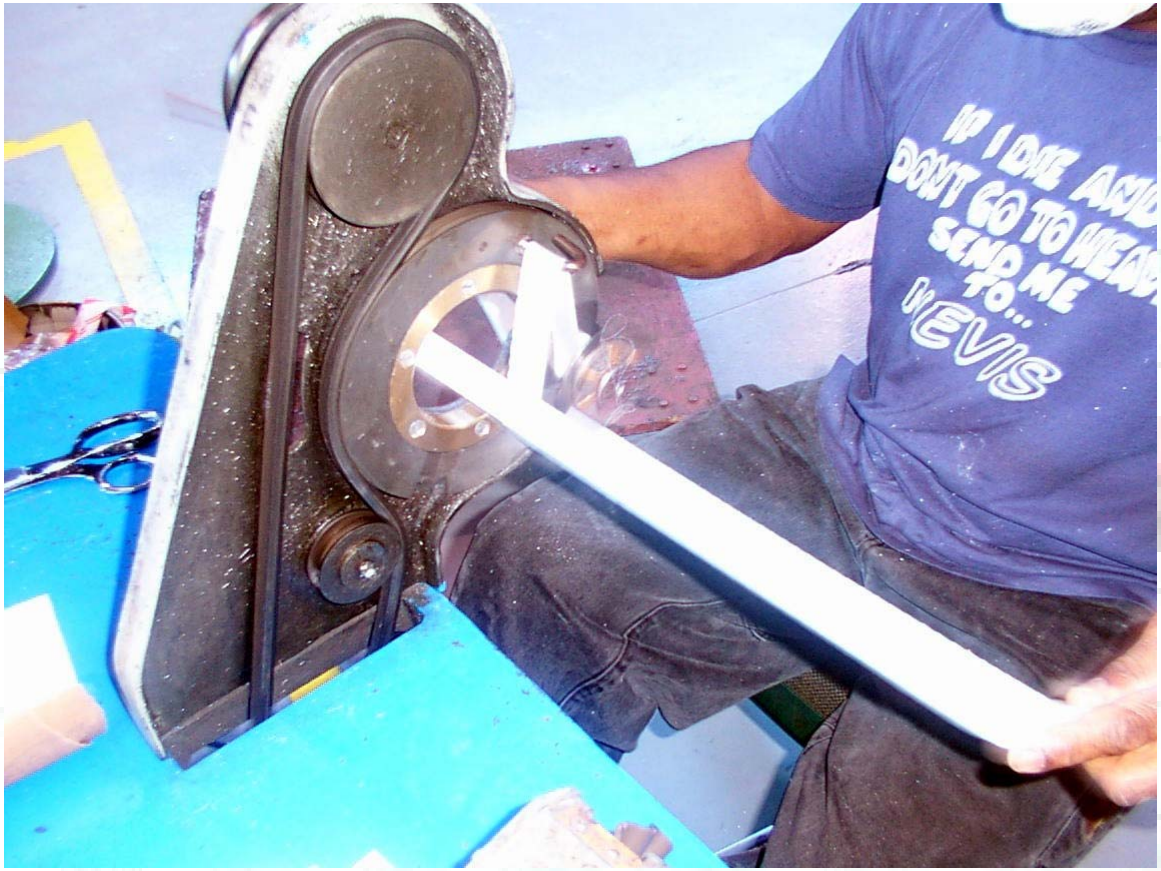
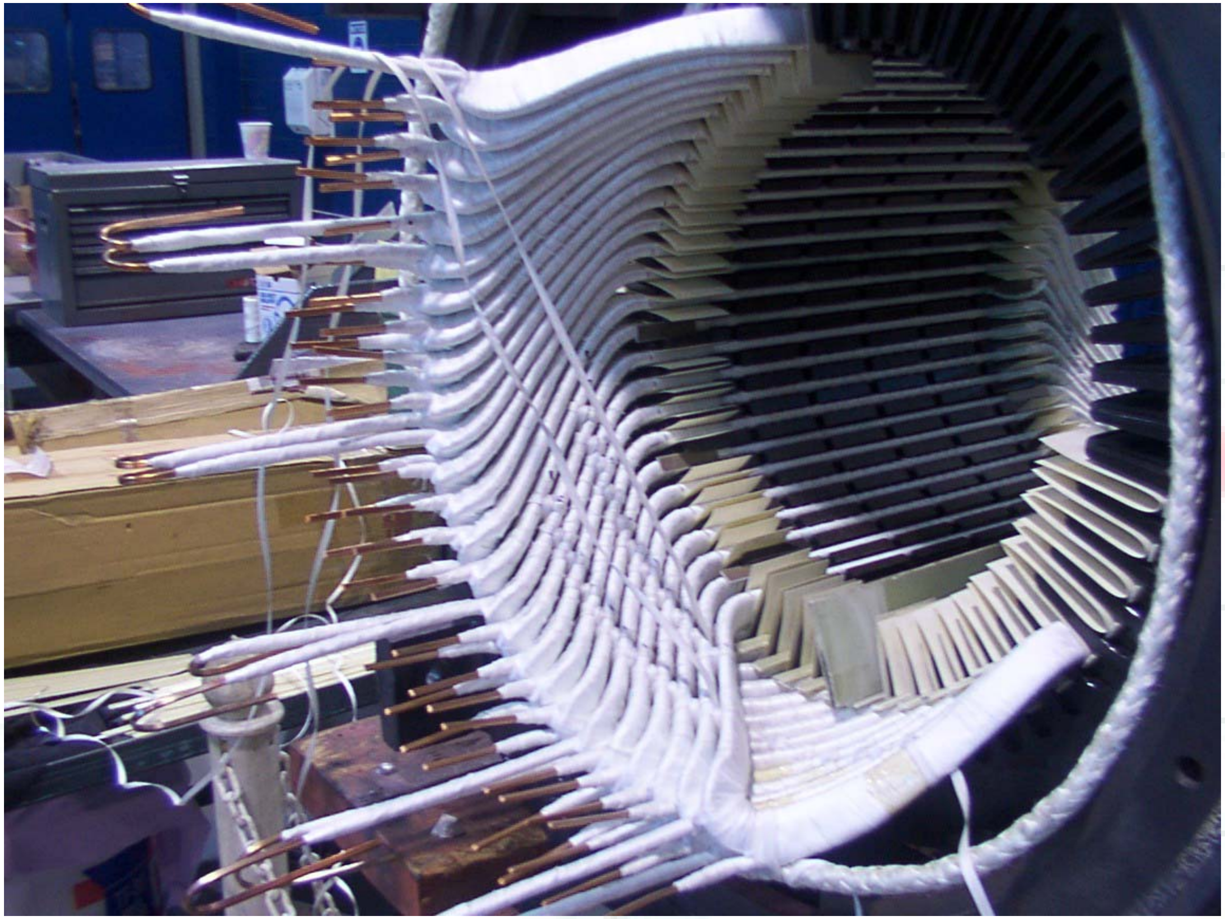
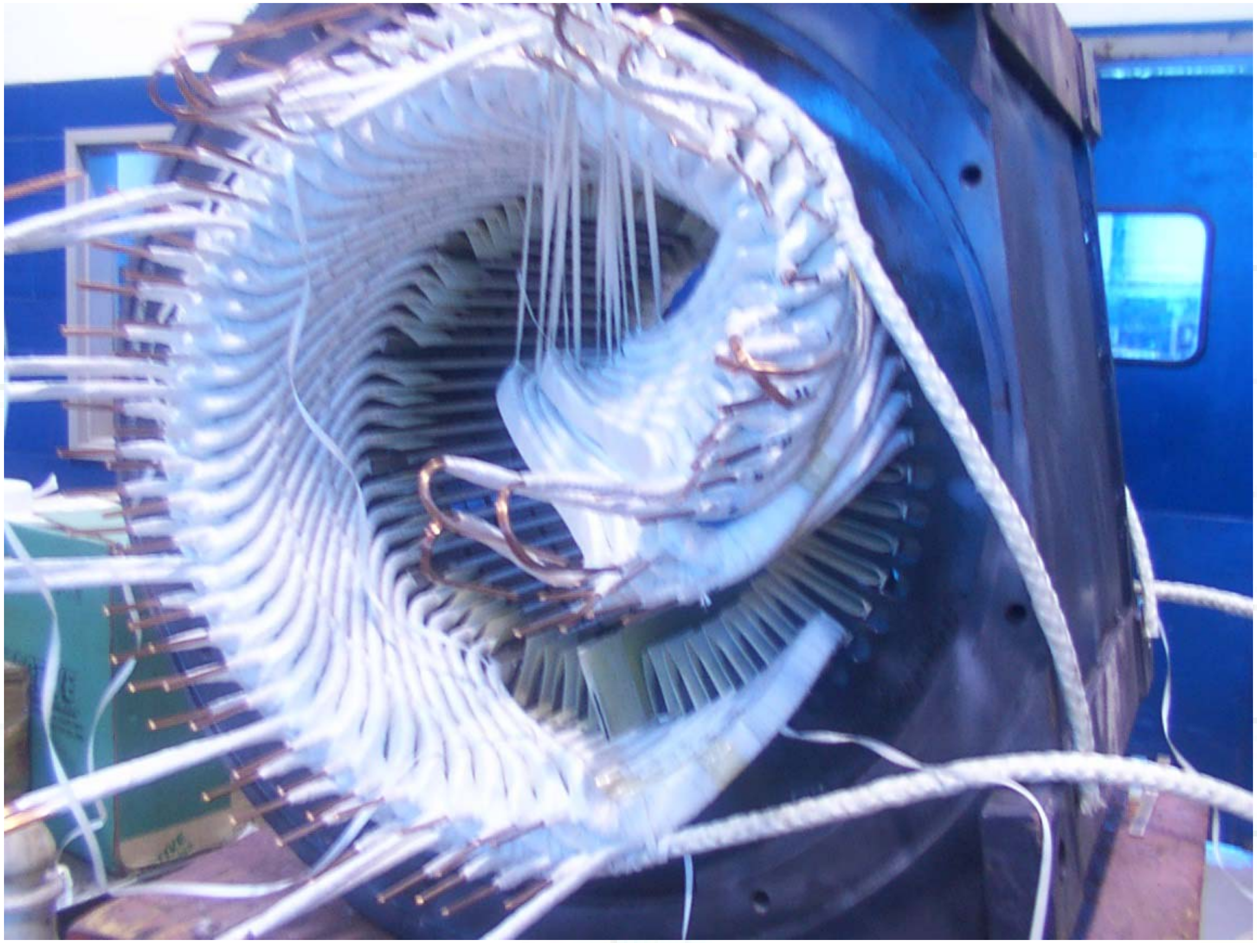
Wrapping with Fiberglass Tape



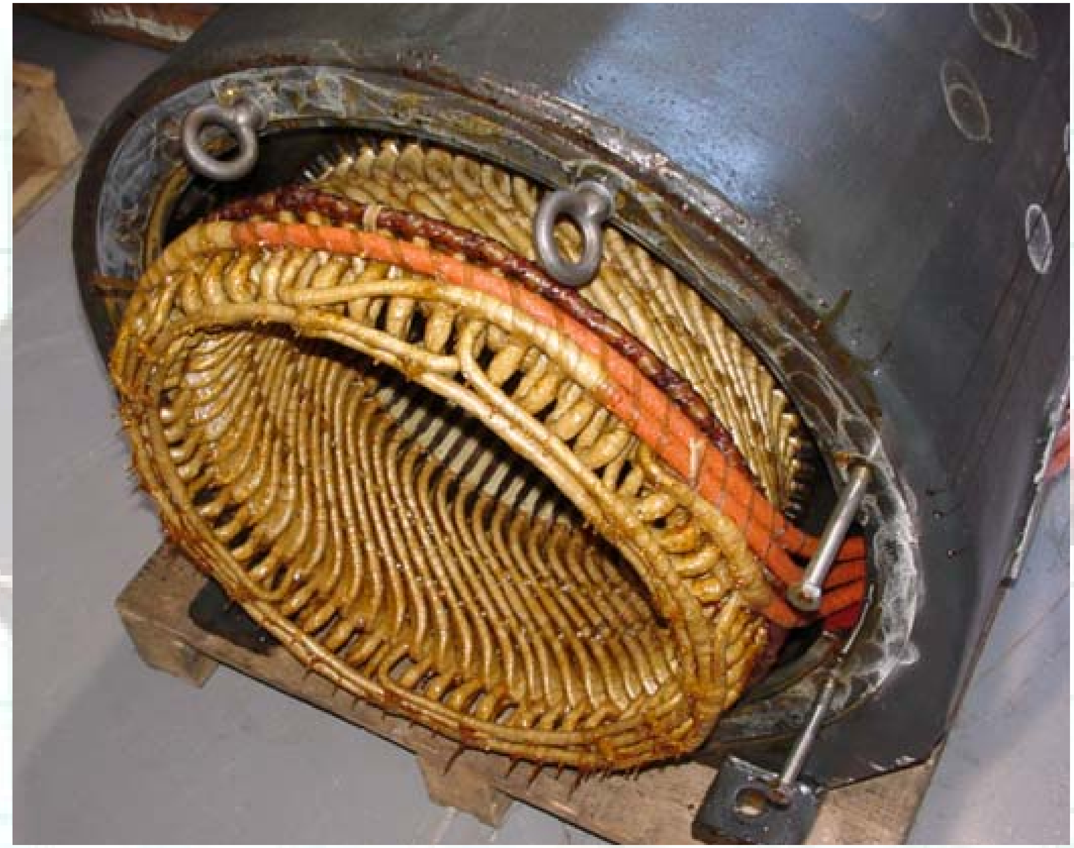
Connection End



Inserting Last Coils



Post-VPI: Connection End



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Factors Affecting the Qualified Life of In-service Motors

- Actual Load vs. Assumed Load
- Number of Starts
- Maintenance Routine (Required vs. Actual)
- Op-tempo (Hours of Operation)
- Actual Ambient Temperature vs. NEMA Standard
- Cleanliness of the Exterior Surfaces
- Cleanliness of the Interior Surfaces

Actual Load vs. Assumed Load

The qualified life of an insulation system is based on the temperature rise of the motor's windings *at full load*. Since it is unlikely that the motor is actually running at full load during operation, the actual load can be used to extend the qualified life of the motor.

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Calculating Temperature Rise for Different Values of Load

IEEE 112 Provides a calculation of temperature rise for varying load conditions for a motor.

$$TR_{actual} = TR_{test} (I_{actual}/I_{test})^2$$

Where:

TR_{actual} = The actual temperature rise of the windings by winding resistance with a load current of I_{actual}

TR_{test} = The tested temperature rise of the windings by winding resistance with a load current of I_{test}

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Actual Load vs. Assumed Load

- EPRI NP-3887 "Life Expectancy of Motors in Mild Nuclear Plant Environments" identifies another method that uses "Life Loss Factors" based on the allowable temperature rise of the insulation, the thermal class of the insulation and the percent load of the motor. The result of the calculation can be used to develop the following table:

Actual Load vs. Assumed Load

Insulation System	Motor Load percent	Hot Spot Temp (°C)	Expected Life percent	Years[c]
Class F (155°C) HIC = 9.3°C[a] ϕ = 1.05eV[b]	110	177	22	0.5
	100	155	100	2.3
	75	124	1000	22.8
	50	100	6013	137
	0	40		12175
	0	20		54036
Class H (180°C) HIC = 8°C[a] ϕ = 1.38eV[b]	110	207	10	0.2
	100	180	100	2.3
	75	142	2690	61.4
	50	113	33300	760
	0	40		426×10^3
	0	20		2.41×10^6
Class H (220°C) HIC = 10°C[a] ϕ = 1.27eV[b]	110	254	10	0.2
	100	220	100	2.3
	75	171	2986	68.2
	50	134	38800	886
	0	40		603×10^3
	0	20		2.41×10^6

Rule of Thumb

- **In 1930, V. M. Montsinger introduced the 10 degree rule concept which states:**

"Thermal life for insulation is halved for each increase of 10 C, or conversely doubled for each decrease of 10 C."

Number of Starts

Each start introduces both thermal and mechanical stresses on the windings and insulation system that are much higher than that of normal operation.

Thermal Stresses

EPRI NP-3887 "Life Expectancy of Motors in Mild Nuclear Plant Environments" provides a conservative calculation for estimating the loss of operational life that can be expected for each motor start due to thermal stress induced during a motor start from full operating temperature.

This calculation results in approximately 1 hour of lost life per start.

Mechanical Stress

- The mechanical stress of starting causes relative movement between insulation system components which can introduce cracking within the insulation system components.
- Though this is an obvious contributor to reduction in the qualified life, no studies have been performed to quantify this reduction.

Maintenance

- IEEE 323 – 2003 States "…This continued capability is ensured through a program that includes, but is not limited to, design control, quality control, qualification, installation, maintenance, periodic testing, and surveillance…"
- IEEE 334 – 1994 States "…This is accomplished through a program that includes, but is not limited to, design, qualification, production quality control, shipping, storage, installation, operation, maintenance, periodic testing, and surveillance of motors to maintain qualification of motors throughout their installed life…"

Maintenance Programs

- A subject for another time