Egyptian program for promoting Industrial Motor Efficiency

Best Practice in Rewinding Three Phase Induction Motors

This material is collected, prepared and presented by

Dr. Hany Elghazaly

Cairo University

UNIDO Expert

UNIDO

Ministry of Trade & Industry
وزارة التجارة والصناعة

Egypt National Cleaner Production Center
مركز تكنولوجيا الإنتاج الأنظف

مركز تحديث الصناعة
INDUSTRIAL MODERNISATION CENTRE

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Agenda

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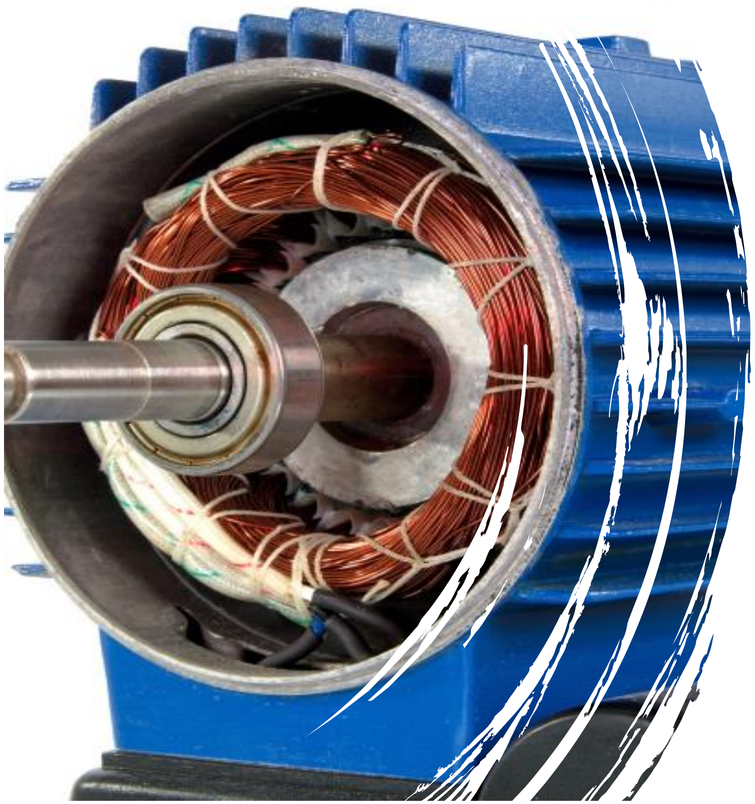
First Day: Basics

- 3 phase induction motor
- Coil wires and their characteristics
- Types of insulation and their properties
- Coils (arithmetic rules – connections and winding)
- Influences of rewinding motors on efficiency
- Motors Testing

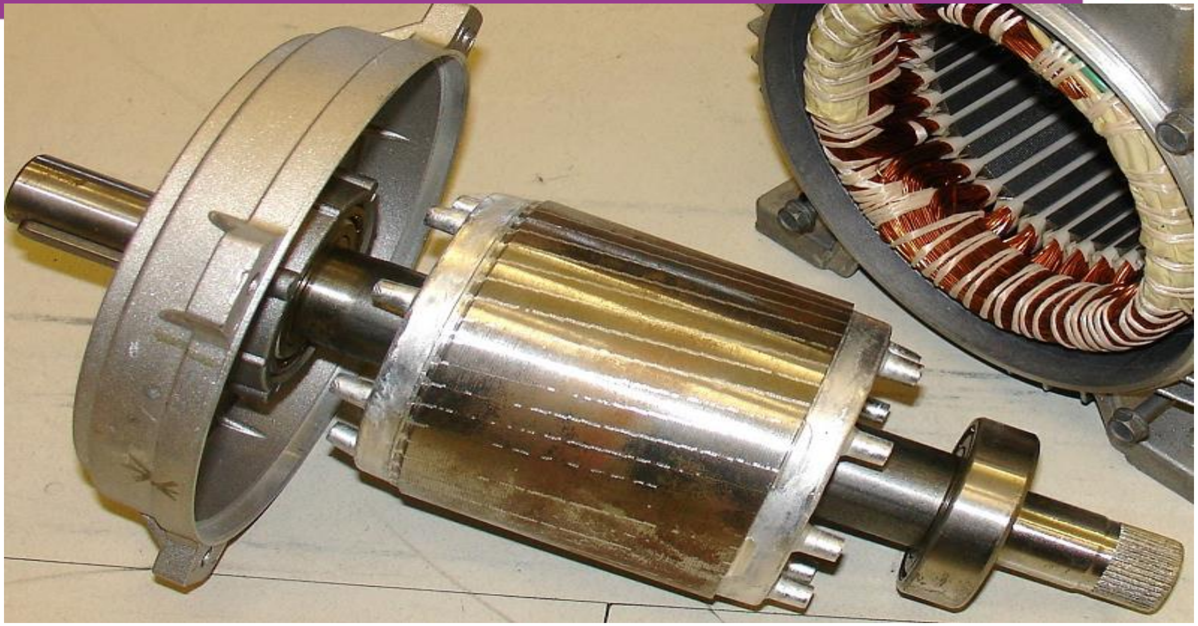
Second Day: Rewinding

- Motor needs for rewinding
- Gathering Motors Data
- Dismantling the Motor
- Documenting and Removing the Old Winding
- Rewinding the Motor
- Mechanical Check and Repair
- Reassembling the Motor

Third Day: On the job training



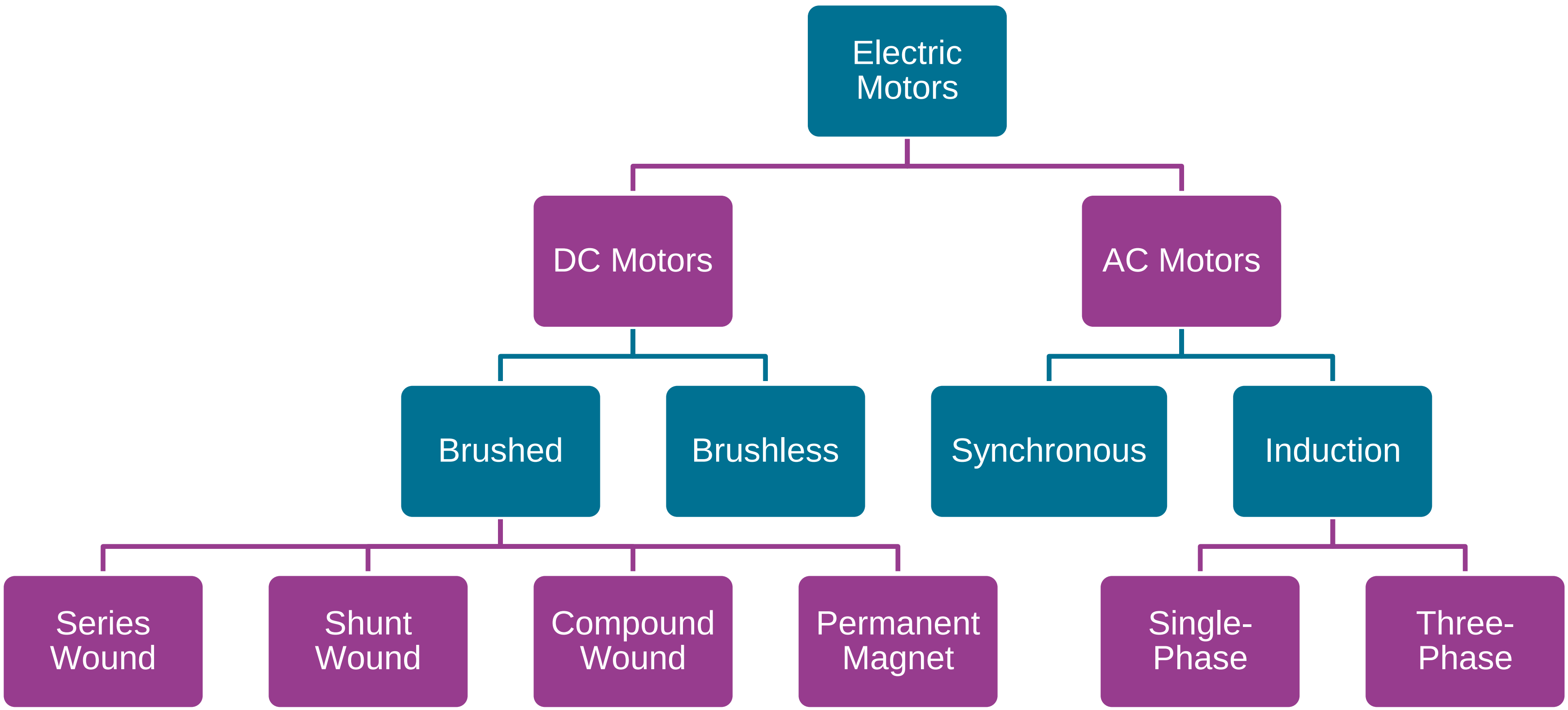
First Day: Basics



First Day: Basics

- **3 phase induction motor**
- **Coil wires and their characteristics**
- **Types of insulation and their properties**
- **Coils (arithmetic rules – connections and winding)**
- **Influences of rewinding motors on efficiency**
- **Motors Testing**

Classifications of Electric Motors



Eelectric motors market in Egypt

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Motors account for more than 60% of electricity consumption in the industrial and commercial sectors. Therefore, they are the main influencer of corporate energy costs. In the industrial sector, studies have shown that :

- 70% of the motors surveyed are small (less than 10 HP (7.5 kW)
- 70% of the motors are three-phase induction motors
- 96% of the industrial companies' rewind motors with no limit to the number of rewinding
- 80% of the rewound motors have a lifetime of fewer than 3 years.

Advantages of 3-phase Induction Motors

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- ✓ Easy to build and cheaper than corresponding dc or synchronous motors
- ✓ Induction motor is robust
- ✓ The motor is driven by the rotational magnetic field
- ✓ No commutator or brush is required
- ✓ Maintenance is relatively easy and at low cost
- ✓ Satisfactory efficiency and reasonable power factor
- ✓ A reasonable torque-speed curve
- ✓ Stable operation under load
- ✓ Range in size from few Watts to several MW

Disadvantages of 3-phase Induction Motors

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- Induction motor has low inherent starting torque
- Draw large starting currents ,typically 6-8 times their full load values
- Speeds not easily controlled as DC motors
- Operate with a poor lagging power factor when lightly loaded

Induction Motor Components

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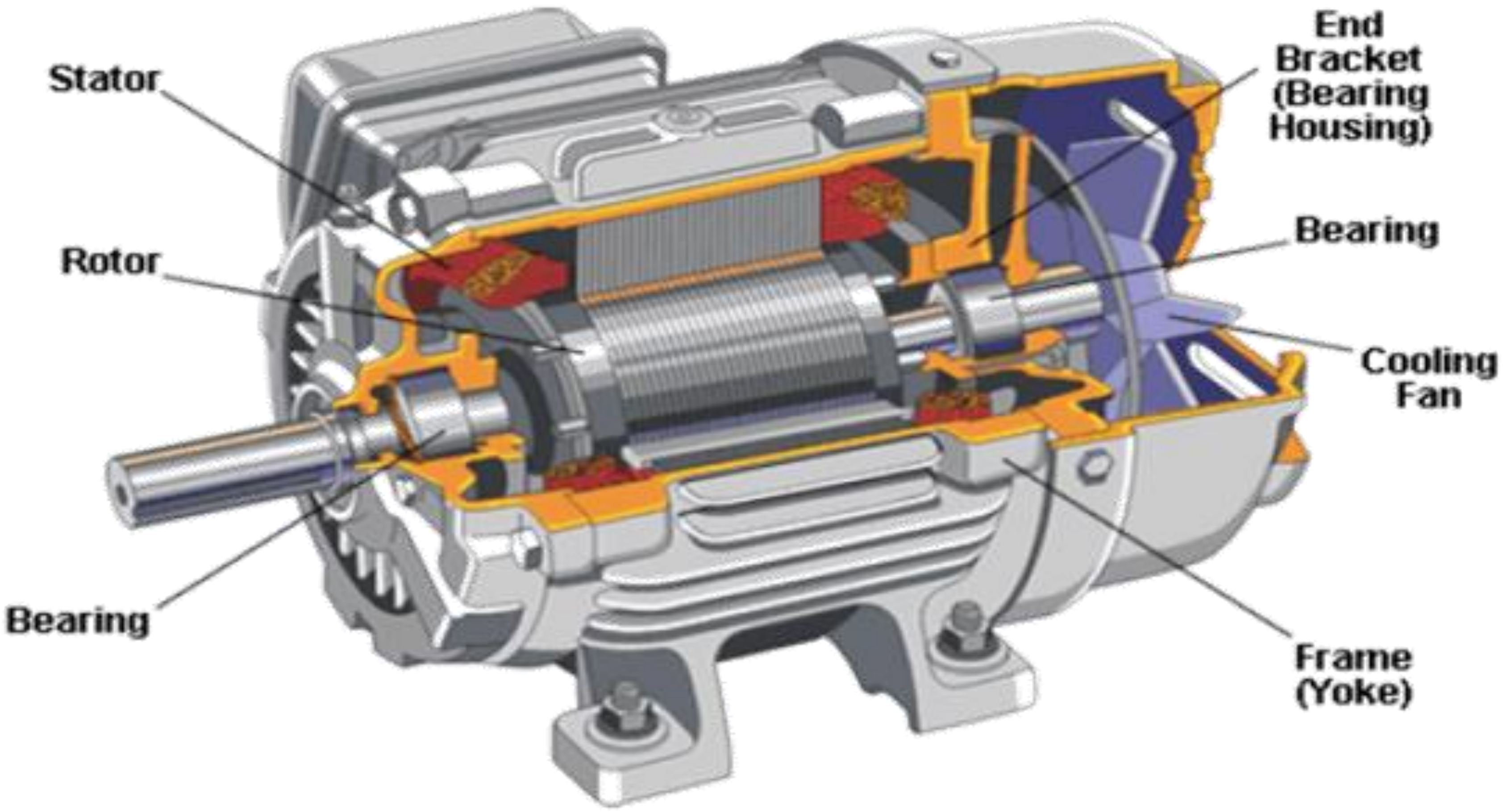
An induction motor has two main parts:

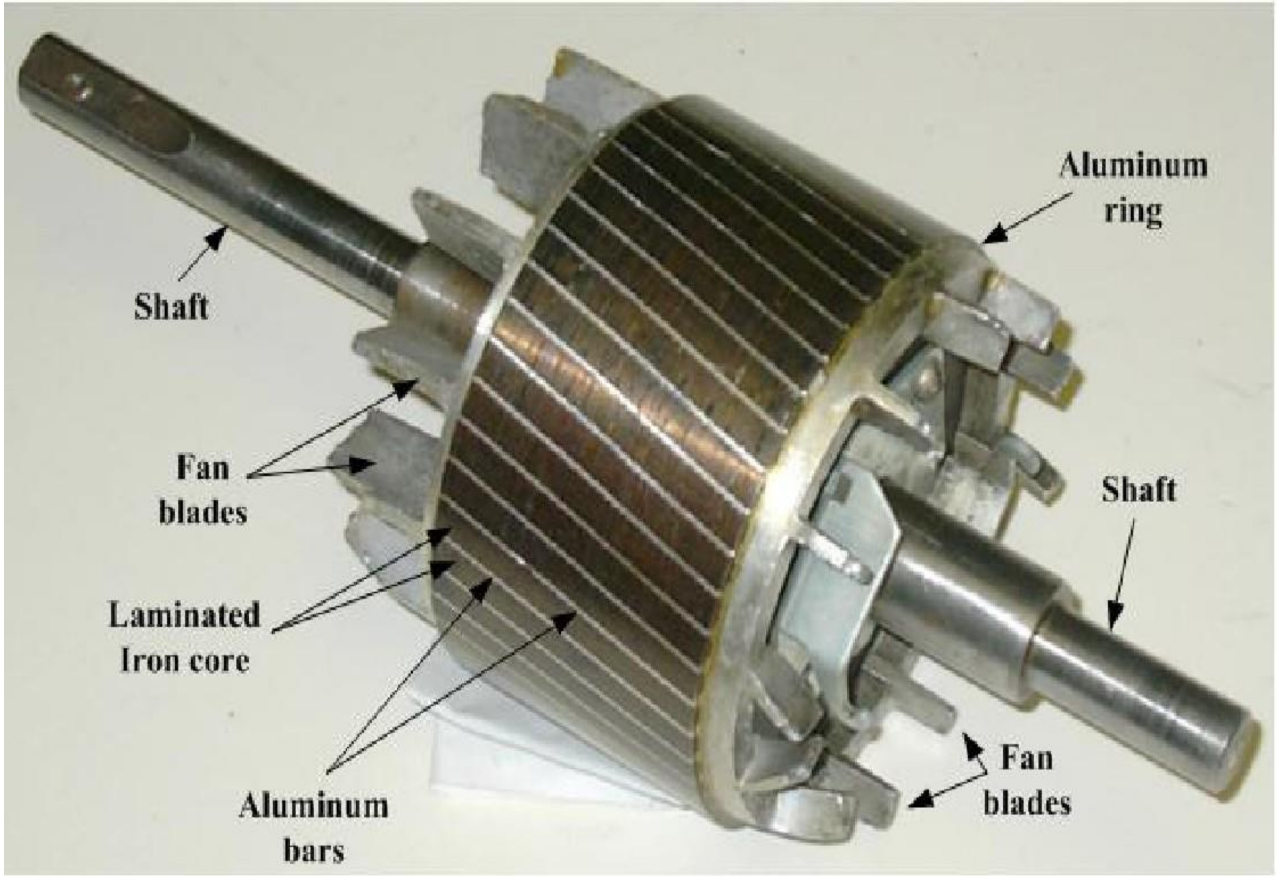
1. **A stator – consisting of a steel frame that supports a hollow ,cylindrical core of stacked laminations. Slots on the internal circumference of the stator house the stator winding.**
2. **A rotor – also composed of punched laminations ,with rotor slots for the rotor winding.**

The rotor is separated from the stator by a small air-gap which ranges from 0.4 mm to 4 mm, depending on the power and the size of the motor.

3-phase Motor Nomenclature



Squirrel-cage Induction Motor



Almost 90% of the three-phase AC Induction motors are of this type.

Theory of Operation

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A rotating and constant resultant magnetic field rotating at a constant speed called synchronous speed (n_s) is produced by any three-phase group of windings displaced in space if the currents flowing through the windings are also displaced in time.

$$n_s = \frac{120}{p} f \ \text{rev/min}$$

Theory of Operation

- ✓ The three fluxes generated by the phase windings are separated by 120° in space and in time. The total flux in the machine is the sum of the three fluxes.
- ✓ The summation of the three ac fluxes results in a rotating flux, which turns with constant speed and has constant amplitude.
- ✓ The rotating flux induces a voltage in the short-circuited bars of the rotor. This voltage drives current through the bars.

Theory of Operation

- ✓ The interaction of the rotating flux and the rotor current generates a force that drives the motor.
- ✓ The force is proportional with the flux density and the rotor bar current.
- ✓ The voltage and current generation in the rotor bar require a speed difference between the rotating field and the rotor.
- ✓ Consequently, the rotor speed is always less than the magnetic field speed.

Direction of Rotation

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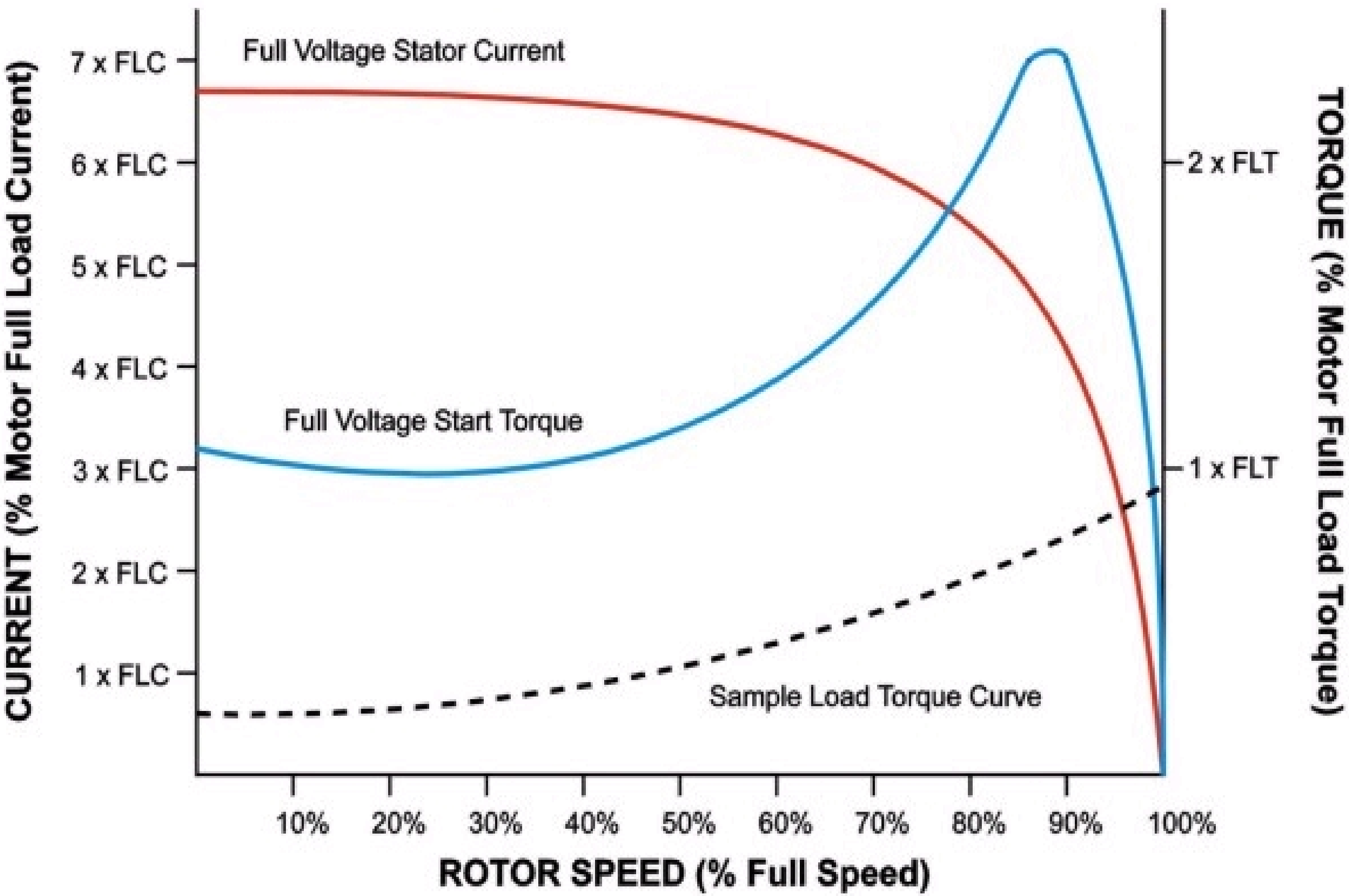
The phase current waveforms follow each other in the sequence A-B-C. This produces a clockwise rotating magnetic field. If we interchange any two of the lines connected to the stator, the new phase sequence will be A-C-B. This will produce a counter clockwise rotating field, reversing the motor direction.

Torque – Speed Curve



Material Used in Motors

Magnetic Materials

- Carbon steels
- Stainless steel
- Silicon steels
- High saturation alloys
- Amorphous ferromagnetic alloys
- Soft magnetic powder composites
- Nanostructured materials
- Ceramic
- Alnico
- Rear Earth

Dielectric Materials

- Paper
- Epoxy
- Plastic

Magnet Wire

- Copper
- Aluminum

Magnetic Wires

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- Wires are made of copper or aluminium, insulated with a layer of varnish. Its quality is proportional to its purity. The higher its purity, the greater its flexibility. Higher purity wires stand a higher current and increase the ease of rewinding with it .
- The wires are of different diameters, starting from 0.5 dc.mm and grading in height until they reach approximately 35 dc.mm -3.5 mm (1 mm = 10 dc.mm). Wires shall be insulated with a single layer of varnish (L), or insulated with double layers of varnish (2L). This insulator, although it withstands high temperatures up to 180 degrees, it isolates one turn from another within the same coil, not the wire from the iron core. Therefore, press-pan paper is placed inside the sewer before the coils are dropped, so that no wire should ever come into contact with the stator body .

Magnetic Wires

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- The wire is measured or purchased based on pure copper or Aluminum without varnish. Therefore, when measuring the diameter of the wire, the varnish layer is removed by any method by burning or peeling without causing corrosion to the copper itself. Otherwise, the wire is measured with varnish and the varnish layer is deducted, which is approximately from 0.01 to 0.04 mm if the insulator is single layer and from 0.05 to 0.08 mm approximately if the insulator is double layer.

Properties of Wires

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Electrical Properties:

- ✓ High conductivity.
- ✓ Low electrical energy dissipated in the form of heat.
- ✓ Low resistivity.
- ✓ Low temperature resistance ratio must be low.

Mechanical Properties:

- ✓ Good ductility to allows the material to be drawn into a wire.
- ✓ Soldering Ability.
- ✓ Resistance to corrosion.
- ✓ Withstand stress and strain.
- ✓ Easy to fabricate.

Economical Factors:

- ✓ Low cost.
- ✓ Easily available.
- ✓ Easy to manufacture.

Applications of Insulating Materials

Where Insulation Must Be Applied?

- ✓ Between conductor /coils and earth (phase-to-earth),
- ✓ Between conductor /coils of different phases (phase-to-phase),
- ✓ Between turns in a coil (inter-turn).

Types and Use of Insulating Materials

Insulation Tapes: Insulation tapes are used to cover the windings (coils) on the overhang side. Tapes are sold as rolls in required lengths. Different types of Insulation tapes available are Cotton tape, PVC tape, Silk tape, Polyester tape, Asbestos tape, Fiber Glass tape, Empire cloth tape and Mica tape.

Insulation sleeves: They are used to cover the joints made at the coil ends and coil leads. It gives physical protection to joints and also provides insulation. They come in rigid and flexible types. They are available for standard wire sizes.

Insulation paper: A variety of insulating papers are available. In motors, it is used to insulate the slots, in between coils. The most often used insulating materials are: Press pan paper, Manila or hemp paper, Triflexil paper, Asbestos paper, Micanite paper.

Insulation cloth: It is inserted between the coils after they are placed in slots. Sometimes it is also used as a slot liner. Empire cloth, Asbestos cloth, Glass cloth, Mica cloth, Micanite- cloth are some of its types.

Types and Use of Insulating Materials

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***Insulating varnishes*:**

Varnish coating is an important component of the insulation system of an electrical machine. Varnishes, of different types, are used in the insulation system of electrical machines for impregnation and finishing applications.

Advantages of these coatings are:

- ✓ Increased mechanical bonding to the winding wires
- ✓ Improved dielectric properties
- ✓ Improved thermal conductivity
- ✓ Protection to the winding against moisture and a chemically corrosive environment.

Varnishes are classified based on:

A. Applications of varnish.
B. Type of (varnish) curing method.
C. Based on the main raw material used in varnish.

Types and Use of Insulating Materials

A. Insulating varnish based on applications:

1. Impregnating varnish
2. Finishing varnishes
3. Inter laminations varnishes
4. Bonding varnishes
5. Special purpose varnishes

B. Insulating varnish based on curing method:

1. Air drying type.
2. Oven baking type

C. Main raw material used**:**

Alkyd Phenolic, Alkyd, Polyurethane, Isophthalic Alkyd, Modified polyester, Epoxyester Melamine, Polyestermide, Epoxy, Phenolic, Phenolic Melamine - based. The above varnishes come in solvent-based and solvent-less based.

Methods of applying varnish:

- Applying a coating with a paint brush.
- Dipping the specimen into varnish.
- Vacuum pressure method.

Types and Use of Insulating Materials

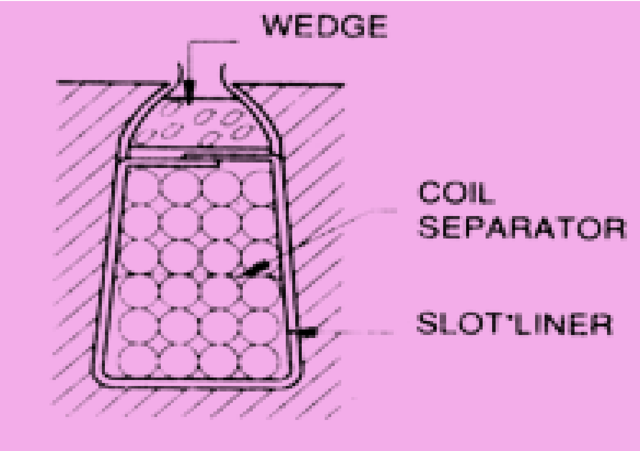
***Impregnating varnish*:**

- The main function of impregnating varnish is not electrical insulation of current-carrying conductors, but to fill the empty spaces in and around windings and to provide mechanical reinforcement of the loose grouping of conductors, even at high temperatures. It also prevents penetration of unwanted substances from the environment.
- This gives the component improved resistance to chemical attacks, to moisture, thus extending its service life.
- They are applied by dipping the component in the varnish, or less often by trickling process.
- These type of varnishes needs to be cured (heated in an oven) at temperatures ranging from 100ºC to 160ºC for 2 to 12 hours. To burn out this varnish you need a temperature between 250ºC and 370ºC depending on the inter laminations' varnish withstand temperature.

Types and Use of Insulating Materials

- ***Inter lamination varnish:*** This varnish is applied to electrical laminations used in electrical machines. This acts as an insulating layer between successive laminations. It is baked in high temperatures vacuum impregnated oven at 350^{o} ⁻C – 450^{o} C for about 5-10 min.
- ***Finishing (coating) varnish***: Finishing varnish is used not to strengthen the windings, but to protect the component from external attack by environmental conditions. They are applied purely as a surface coating and are characterized by outstanding film-forming properties. Often applied by paint brush or sprayed in repair shops after rewinding works. They are mostly air-drying types. It takes almost a day to completely cure.
- ***Binder varnish:*** This type of varnish is used as the bonding agent between two insulating materials. Mechanically weak materials when bonded show good rigidity. It is baked at temperatures of about 120oc to 450oc for a duration of 3min. to 60 min, depending on the grade of the varnish.

Slot Insulation



Slot Liner: The slot liner is cut to the inner dimensions of the slots and projected on either side of the slots. The edges of the slot liner are folded on both end to prevent them from sliding in the slots.

Coil Separator: When multilayer windings are used, an insulation sheet tis used to separate the winding coils from each other and should be extended on both side of the slot.

Insulation Tape otni deppord era yeht retfa slioc eht neewteb detresni si tI :
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Wedge: It is a solid insulation piece like bamboo or fiber glass used to prevent the conductors from coming out of the slots. It should be tightly held in the slots.

Electrical Insulation Classes

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Class Y: 90º C: Paper, cotton, silk, natural rubber, polyvinyl chloride, etc. without impregnation.

Class A: 105ºC: Same as class Y but impregnated, plus nylon.

Class E: 120ºC: Polyethylene, terephthalate, (terylene fibre, melinex film), cellulose triacetate, polyvinyl acetate enamel.

Class B: 130ºC: Mica, fiberglass (alkali-free aluminum borosilicate), bituminized asbestos, bakelite, polyester enamel.

Class F: 155º C: As class B but with alkyd and epoxy-based resins, polyurethane.

Class H: 180ºC: Class B with a silicone resin binder, silicone rubber, aromatic polyamide (Nomex paper and fiber), polyamide film (enamel, varnish and film) and Estermide enamel.

Class C: Above 180ºC: As class B but with suitable non-organic binders; (Teflon, Mica, Micanite, Glass, Ceramics, Polytetrafluoroethylene).

Electrical Insulation Classes

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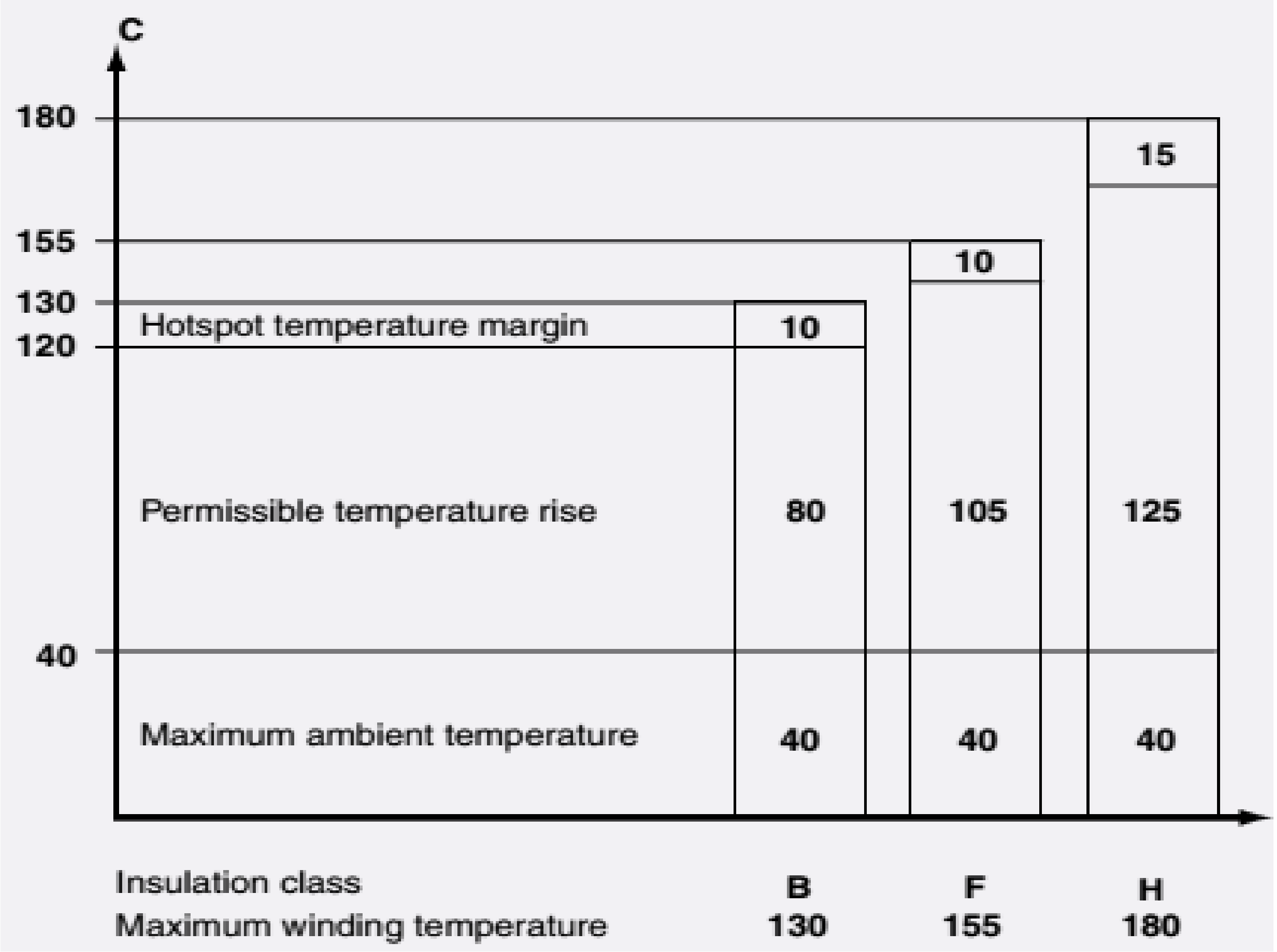
The standard IEC 60085 gives the maximum operation temperature for each thermal class.

Thermal classes for insulation systems	A	E	B	F	H
Maximum operation temperature (°C)	105	120	130	155	180

Electrical Insulation Classes



Reasons for Rewinding Motors

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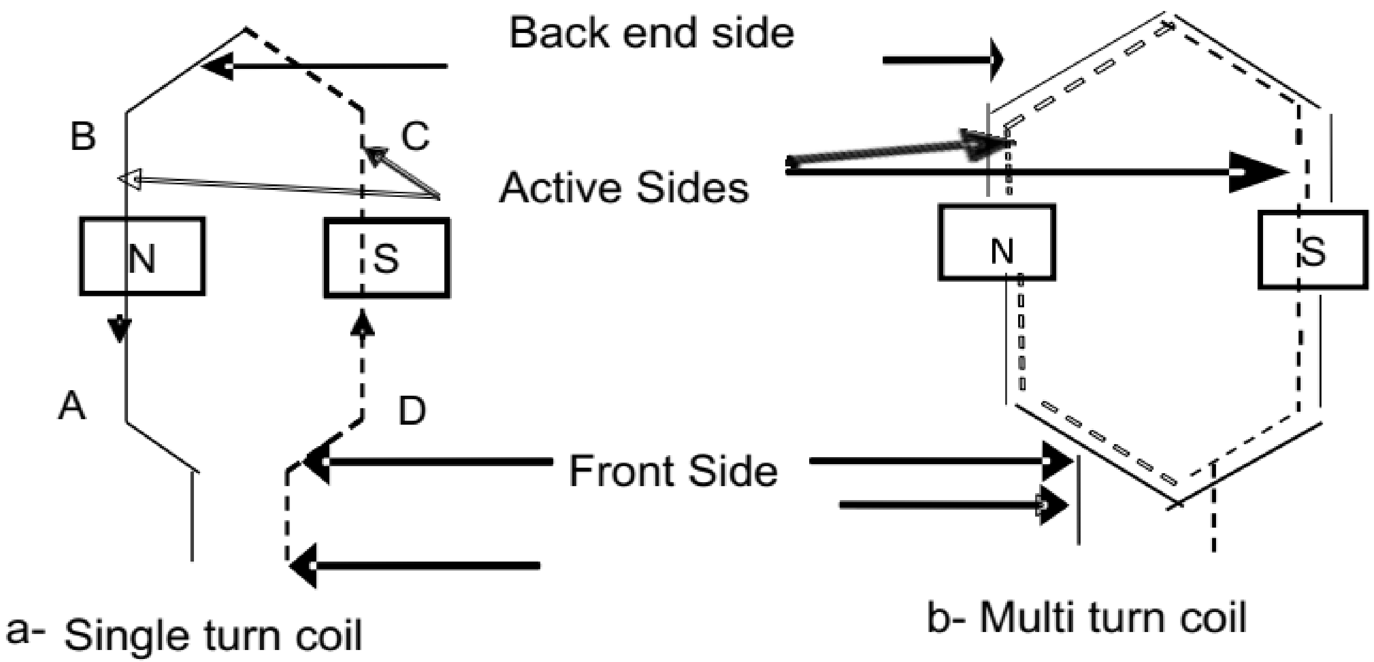
- There can be a wide variety of issues behind motor failures that necessitate rewinding, and most of them make themselves known in the form of failed insulation and/or grounded/shorted coils.
- Insulation failures can take several different forms, including windings that have shorted turn-to-turn or phase-to-phase, coil-to-coil, or grounded at the edge of the slot. These particular issues can usually be traced back to contamination, abrasion, voltage surges, the overall age of the machine, or vibration.
- Thermal deterioration is another common cause of motor insulation failures. It is caused when the insulation overheats due to poor connections in the motor terminal, a locked rotor resulting in high currents in the stator, excessive load demands that exceed the motor's rating, or excessive reversals and starts.

Windings' Configurations



Coil Groups: One or more coils connected in series are called coil groups. The number of coil groups per phase is equal to the number of poles.

Windings' Configurations

Pole Pitch**:** **It is the distance between the centers of two adjacent opposite poles. It is measured in terms of the number of slots.**

One pole pitch = $\dfrac{\textit{Number of slots}}{\textit{Number of Poles}}$ $= S/P = 180^{o}_{ed}$

where S = number of slots P = Number of Poles
ed = electrical degree

Coil Span or Coil Pitch: **It is the distance between the two active sides of the same coil under adjacent opposite poles. It is expressed in terms of the number of slots per pole or electrical degrees.**

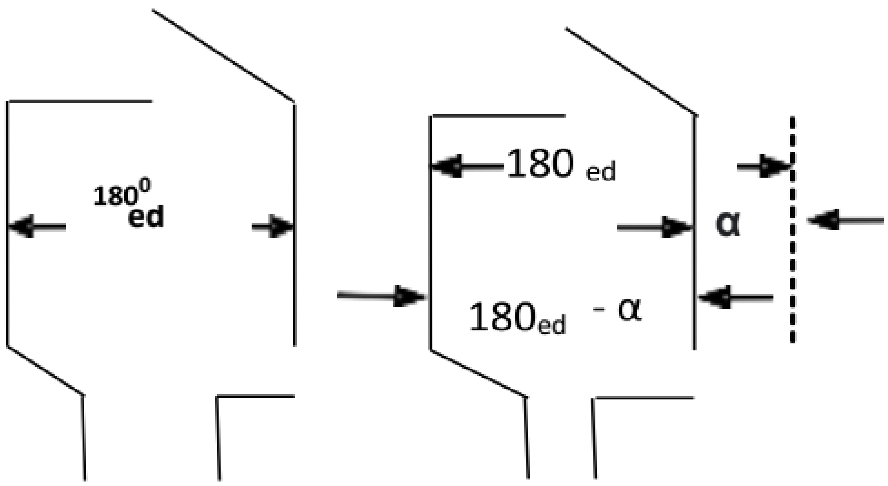
Windings' Configurations

Full Pitch Coil: A coil having a coil span equal to 180_{ed} Is called a full pitch coil.

Short pitch coil: A coil having a coil span less than 180_{ed} by an angle â, is called a short pitch coil, or fractional pitch coil. It is also called a chorded coil.

á= 0 for full pitch winding

á = xâ for short pitch winding



Also â = 180/ (S/P)

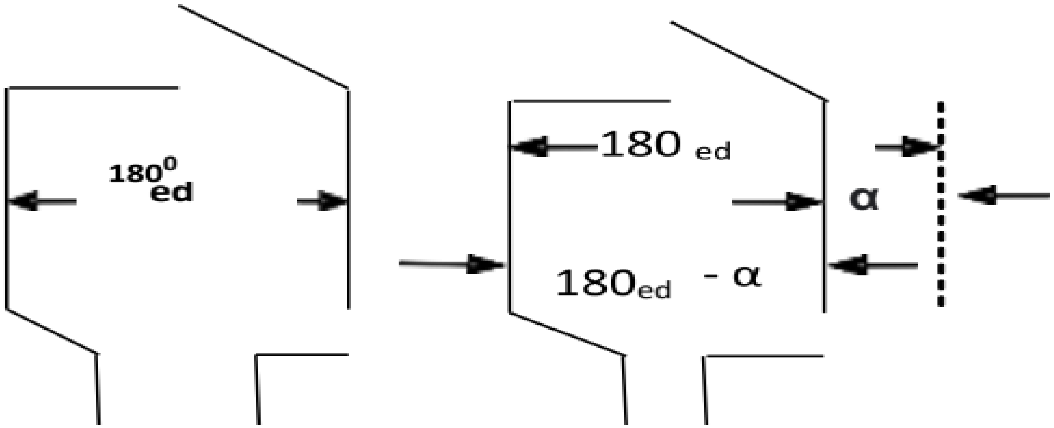
Where:

á = short pitch angle or an angle less than 180_{ed}

â = angle between adjacent slots

x = 1, 2, 3, . . . an integer

Windings' Configurations



***Pitch factor or coil span factor or chording factor, KP*:**

When the two sides of the same coil are short-pitched by an angle á, the emf induced in the two coil sides have a phase angle difference of <u>α</u> ^{0}. Due to phase angle difference, the actual emf is reduced by a factor <u>cos α/2</u> and is called pitch factor, coil span factor or chording factor. **Kp = cos α / 2**

Windings' Configurations

Kd =

Distribution Factor, Kd : It is defined as the ratio of phasor addition of emf induced in all the coils distributed in m slots under one pole region to their arithmetic addition of emf induced in all the coils distributed in m slots under one pole region.

$$K_d = \frac{\sin\left(\frac{m\beta}{2}\right)}{m\sin\left(\frac{\beta}{2}\right)} \qquad m = \frac{s}{3p} \qquad \beta = \frac{180}{S/P}$$

Example: Compute the distribution factor for a 3 phase 4 pole ac machine wound in 36 slots with a coil span of 140^{o}_{ed}.

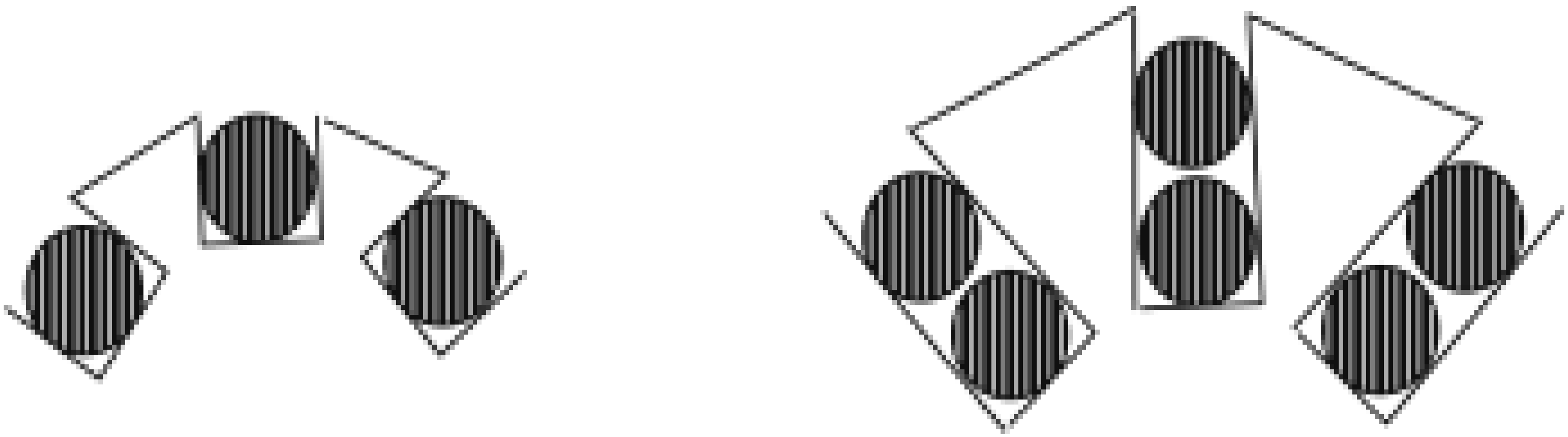
Solution: $m = \frac{36}{3\times4} = 3$

The angle between adjacent slots:

β = 180/(S/P) = 180/(36/4) = 20^{o}_{ed}

Then: $K_d = 0.96$

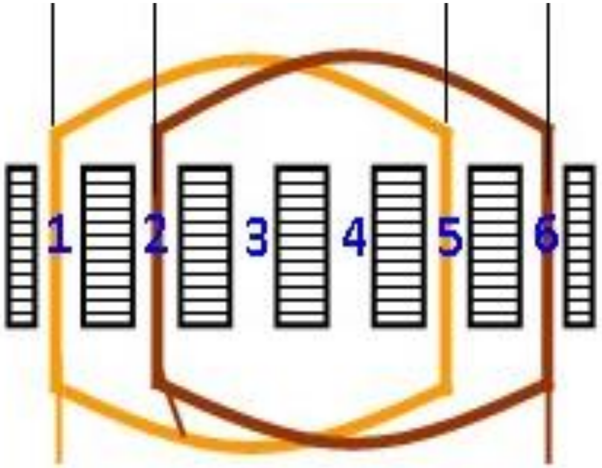
Single Layer and Double Layer Winding



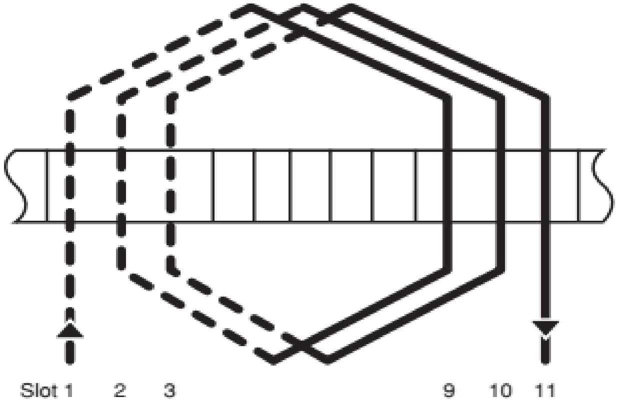
SINGLE LAYER WINDING: In this type of winding, as shown in Figure (a), each slot contains only one coil side. It means a coil occupies two complete slots. The number of coils in the machine is equal to half the number of slots in the stator, or rotor and armature.

DOUBLE LAYER WINDING: In this type, as shown in Figure (b), each slot contains two coil sides, housed one over the other. The number of coils is equal to the number of slots in the stator and armature.

Coil Winding



Lap winding
Equal coil Pitch

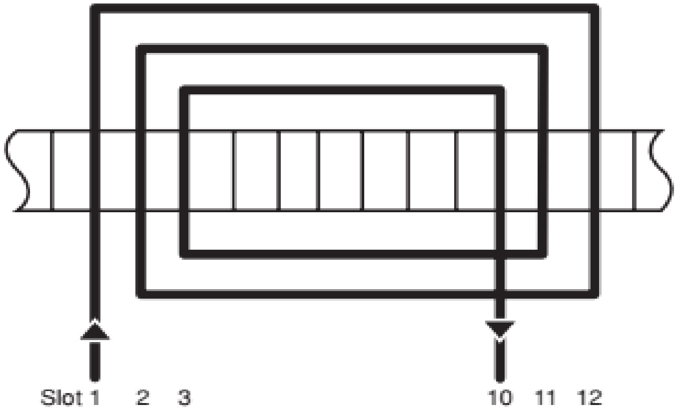


Double-layer lap winding
Winding short-pitched 1-9 (span 8)
Dotted lines indicate coil sides in the lower half of slots

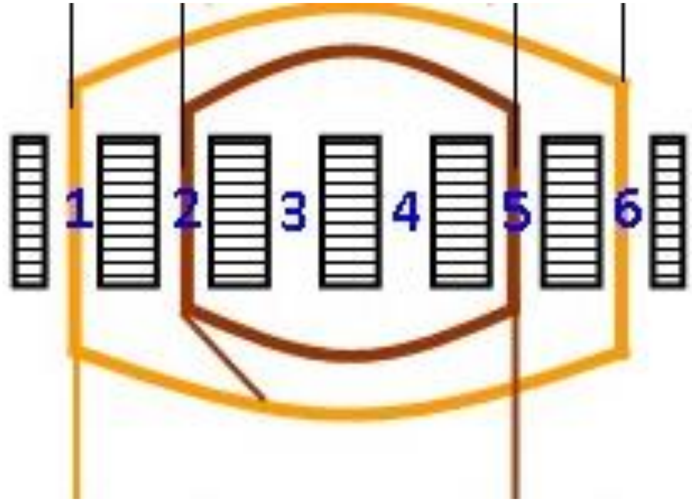
Lap Winding: Lap winding can be used in a single layer or double layer windings. When the finishing end of the first coil is connected to the starting end of the next coil which starts under the same pole where the first coil started is called lap winding.

Coil Winding

Unequal Coil Pitch



Concentric Winding
Unequal Coil Pitch



Group concentric winding
Coil pitch 1-8,10,12 (spans 7,9,11)

Concentric Winding: Concentric windings are single layer windings. This winding has two or more coils in a group and the coils in each group have the same center. In each group, the coil pitch is not equal and therefore do not overlap each other. The coil span of the individual coils is different. The coil span of some coils is more than a pole pitch while the span of others is equal to or less than the pole pitch.

Connecting Coil Groups

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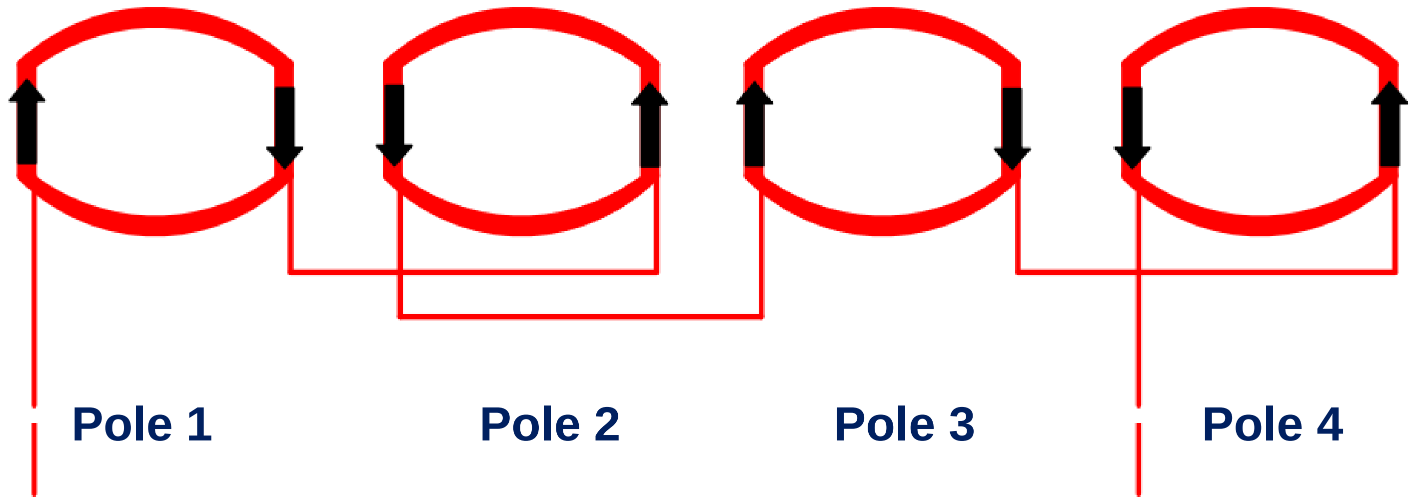
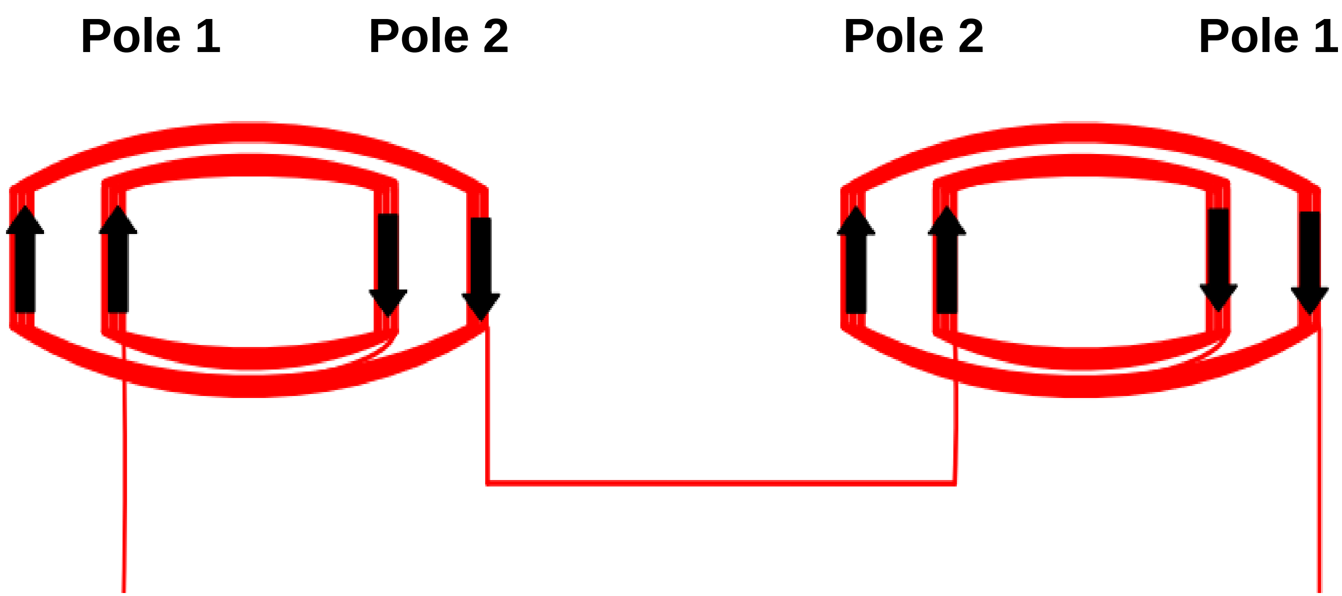


Whole Coil Winding: It is the coil winding in which the number of coils per phase is equal to the number of poles in the machines. The connections between the coils are finishing end to finishing end and starting end with starting end.

Connecting Coil Groups



Half Coil Winding: It is that winding in which the number of coils per phase is equal to half the number of poles in the machines. The connection between the coils is the finishing end of the first group is connected to the starting end of the next group, which starts from the next adjacent pole where the first coil started.

Mathematical Rules for Winding Motors

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1. No. of coils / phase $= \frac{\text{Total No. of coils}}{\text{No.of Phase}}$

   = ... coils

2. No. of coils / phase / poles $= \frac{\text{Total No. of coils}}{\text{No.of Phase} \times \text{No. of Poles}}$

   = ... slots/poles.

3. Pole pitch $= \frac{\text{No. of slots}}{\text{No.of Poles}} =$ = ... slots / poles

4. Coil pitch possible

   A ....

   B ....

   C ....

5. Coil pitch as per the data collection is ....
6. Coil pitch selected is ....

   (short chorded/full pitched/ long chorded)

7. Total electrical degrees = 180° x No. of poles

   = 180° x .... = ...

Mathematical Rules for Winding Motors

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8. Slot distance in degree $= \dfrac{\text{Total electrical degree}}{\text{No. of Slots}}$

9. Reqd. displacement between phases in terms of slots $= \dfrac{120}{\text{Slot distance in degree}}$

10. Winding sequcence

If 1st phase starts in the ....

2nd phase starts in the ....

3rd phase starts in the ....

Torque, Flux and Winding Rules

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$$E = 4.44 \times f \times N \times F \times K_d \times K_p$$

Where E = back emf/phase

f = frequency

N = number of series turns/phase

F = magnetic flux/pole

K_d = winding distribution factor

K_p = winding pitch factor

Rewinding Process

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Electric motor rewinding involves three basic steps:

- ✓ **removal or stripping of the winding (coils),**
- ✓ **inserting and connecting new winding (coils), and**
- ✓ **insulating the complete winding.**

The rewinding process is not necessarily as simple as it may sound. This manual will give you the basics you may need to learn and apply most of the best practices in this field.

Habits of Repair Shop Workers

Positive Habits :

- ✓ Concentric coil assemblies are rarely used by motors maintenance and repair shops .
- ✓ Repair shop workers are often more careful about the exact layers of wire in the coils than the manufacturers .
- ✓ Repair shops tend to use larger sizes of connecting wires and more phase insulation and reinforcement .

Habits of Repair Shop Workers

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Negative Habits:

- Workers in repair shops use hand tools that scratch the insulator and lighten the teeth of the plates .
- Damage to the iron core when cutting and removing old files. Burn insulation with flame .
- Use longer wires than the original on the front and rear ends, which increases loss .
- Error in measuring the cross-sectional area of the copper wire .
- Using varnish or manual immersion methods instead of impregnation furnace .
- Failure to perform mechanical maintenance, which leads to rapid engine damage .
- Extending the slot insulation beyond the ends of the slots more than is necessary, which leads to pressure on the ends of the slot edge. Replacement of a double layer winding with a single layer winding .

Rewinding Process Improvement

- Copy (duplicate) rewinding:
- Minimize the length of the coil extensions.
- Increase the copper cross-sectional area in each coil.
- The series windings should be suitably short pitched.
- Do not extend the slot insulator beyond the ends of the slots more than is necessary .
- Use modern tools and equipment .
- Follow international best practices for motor rewinding .

Copying Rewinding

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- ✓ Use the same winding configuration.
- ✓ Keep coil extensions as short as practical.
- ✓ Same (preferably less) length of overhang.
- ✓ Use the same coil pitch (or pitches).
- ✓ Use the same turns/coil.
- ✓ Use the same (preferably larger) copper cross-sectional area.
- ✓ Use the same or shorter Mean length of turn (MLT)
- ✓ Use same or lower winding resistance (temperature corrected).

Electric Motor Efficiency

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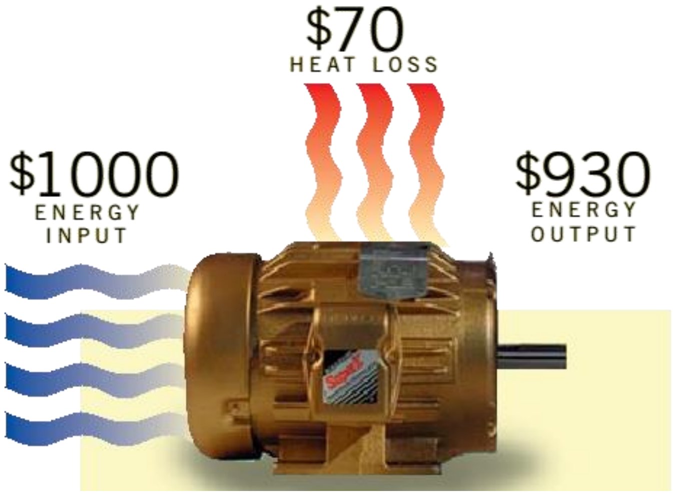
$$efficiency = \frac{Useful\ Power}{Input\ Power}$$



$$efficiency = \frac{Useful\ Power}{Useful\ Power + Losses}$$

Electric Motor Losses

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- **The electrical losses (copper losses)** are caused by heating from the current flow through the resistance of the stator and rotor windings, are expressed by I^2R .
- **The no load losses (Magnetic losses)** are due to eddy currents and hysteresis in the laminations of the stator and rotor.
- **The mechanical losses** are due to friction in the bearings, ventilation and windage losses.
- **The brush contact losses** occur due to the voltage drop between the brushes and commutator (only for motors with brushes).
- **Stray load losses** result from the leakage flux, harmonics of the air gap flux density.

Electric Motor Losses

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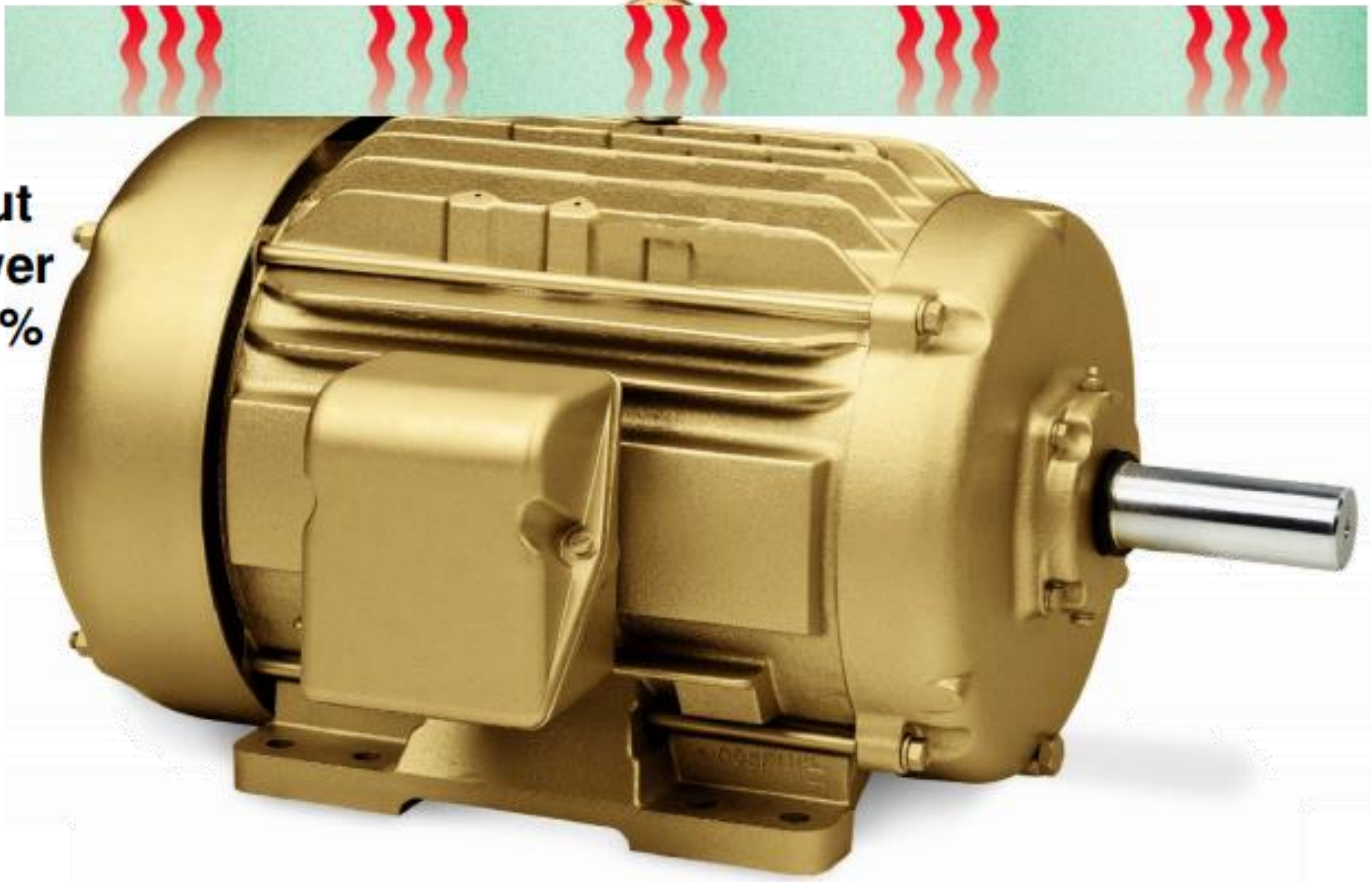
Iron core losses | Stator resistance | Rotor resistance | Windage & friction | Stray load losses

Total Losses 7.6%



Input Power 100%

Output Power 92.4%

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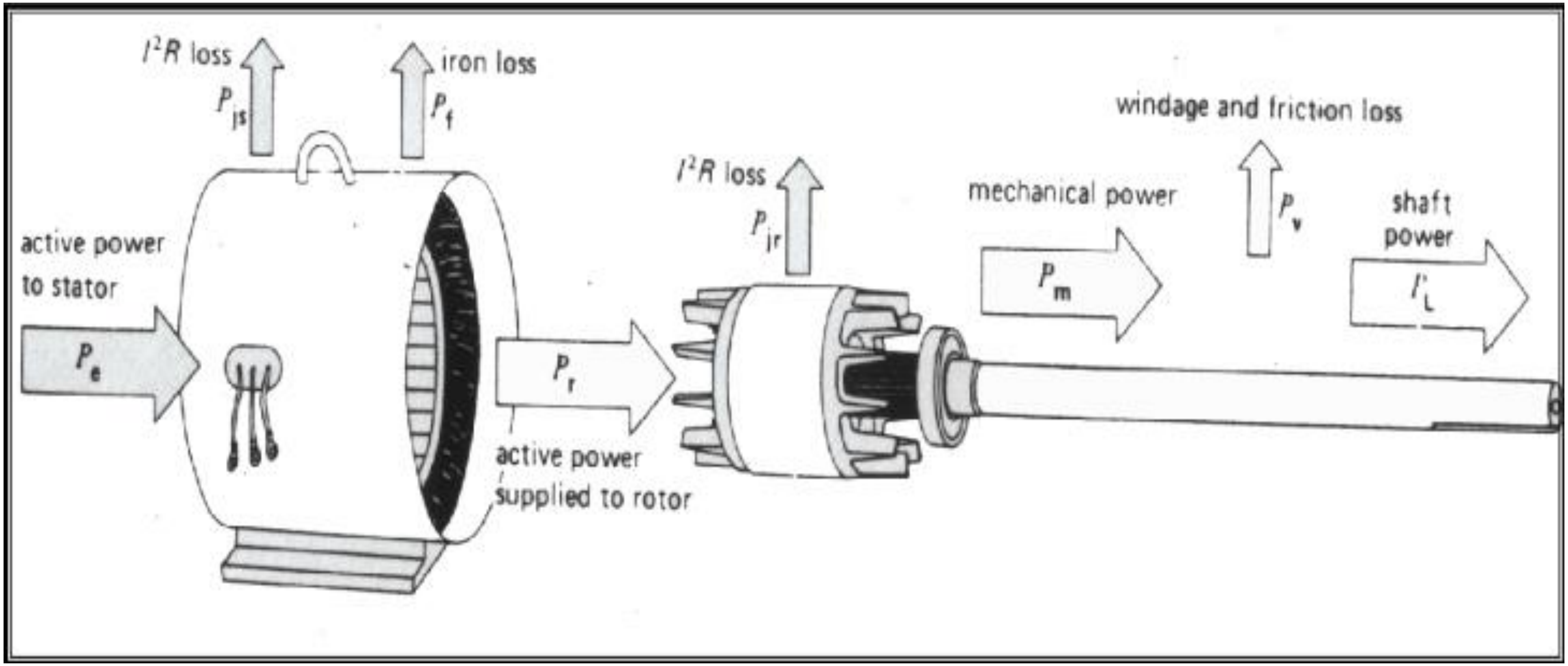
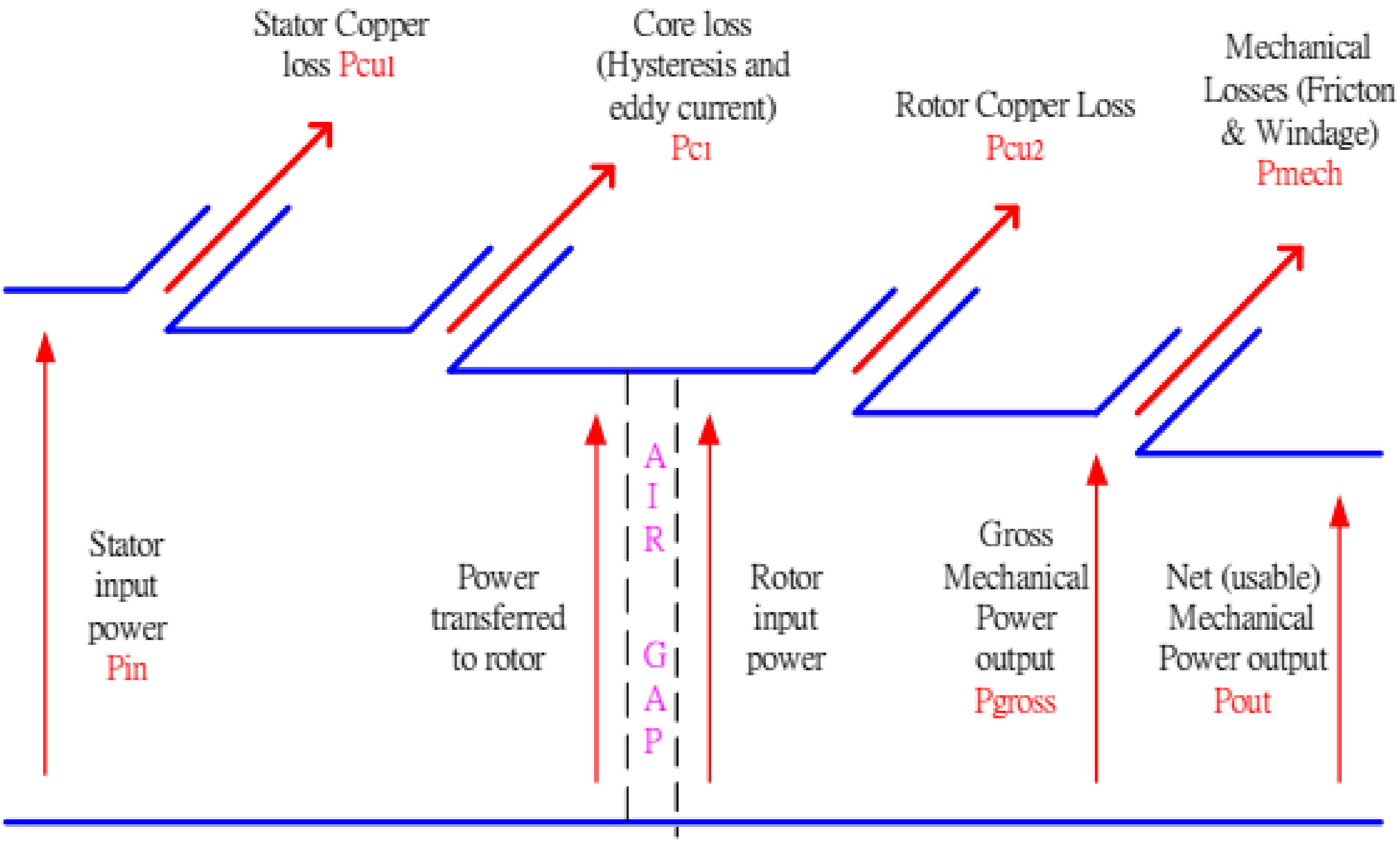
Power Flow Diagram



Sankey Diagram for Motors



Motor Losses

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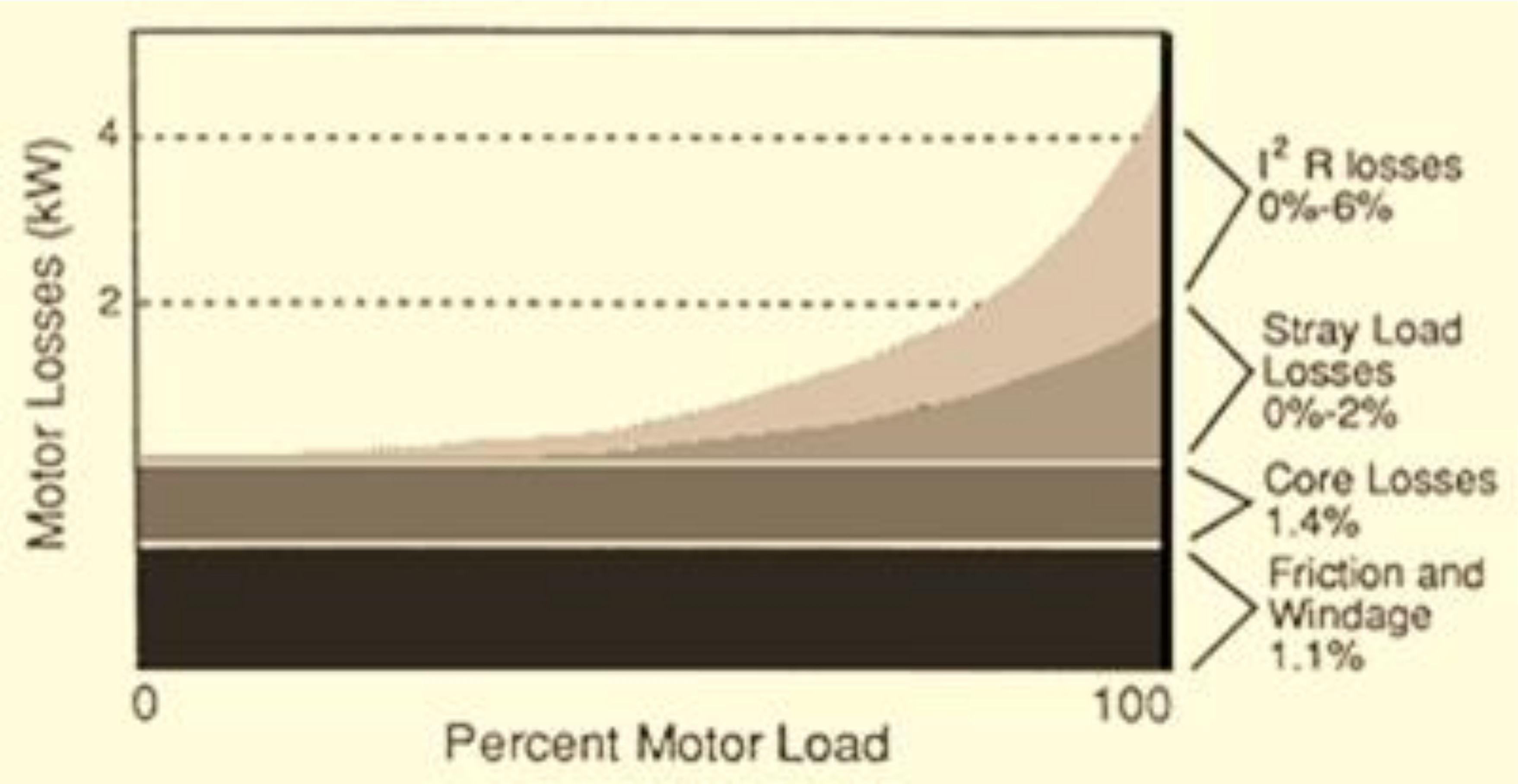
Motor Losses- 50 hp Induction Motor



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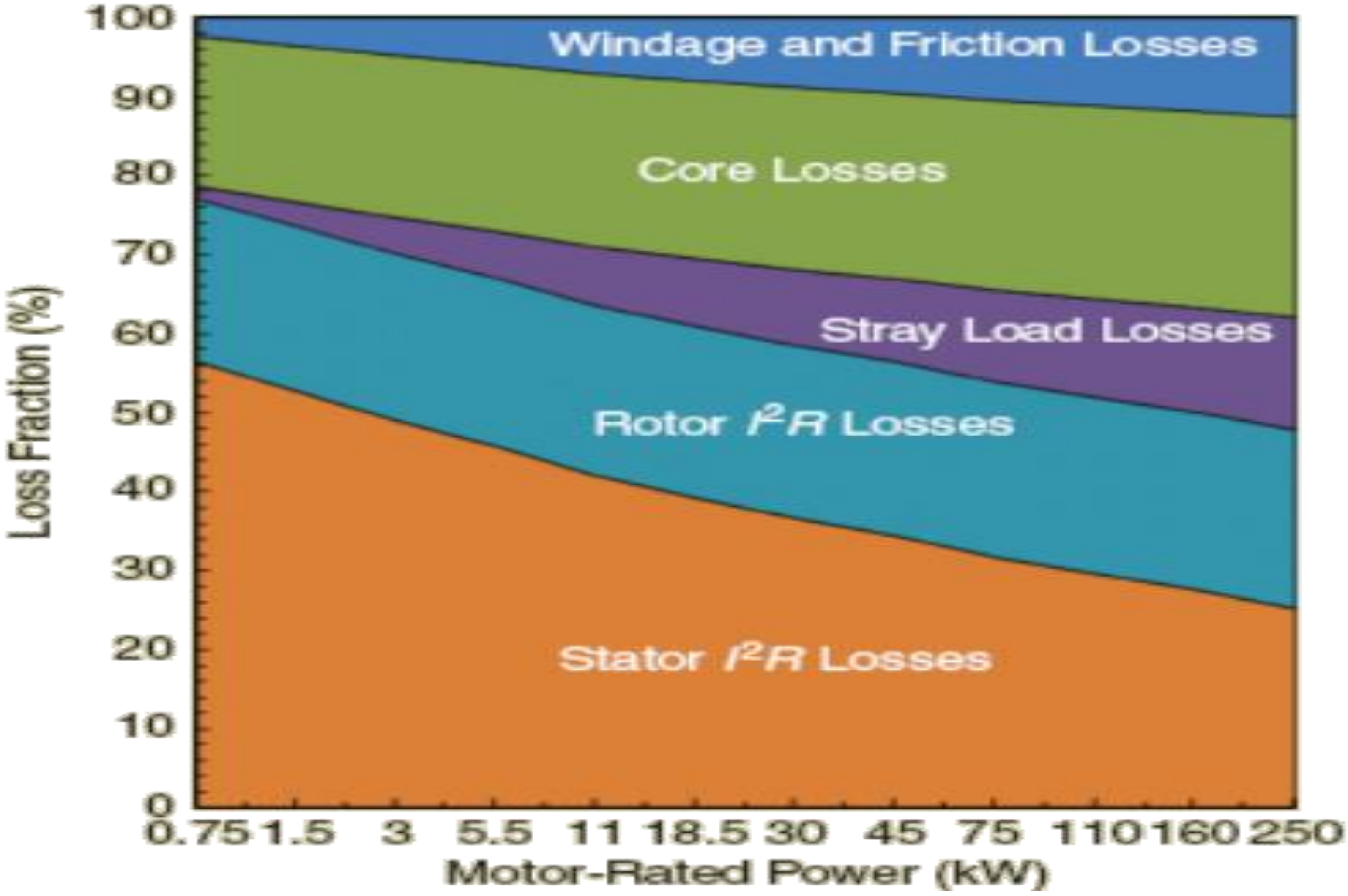
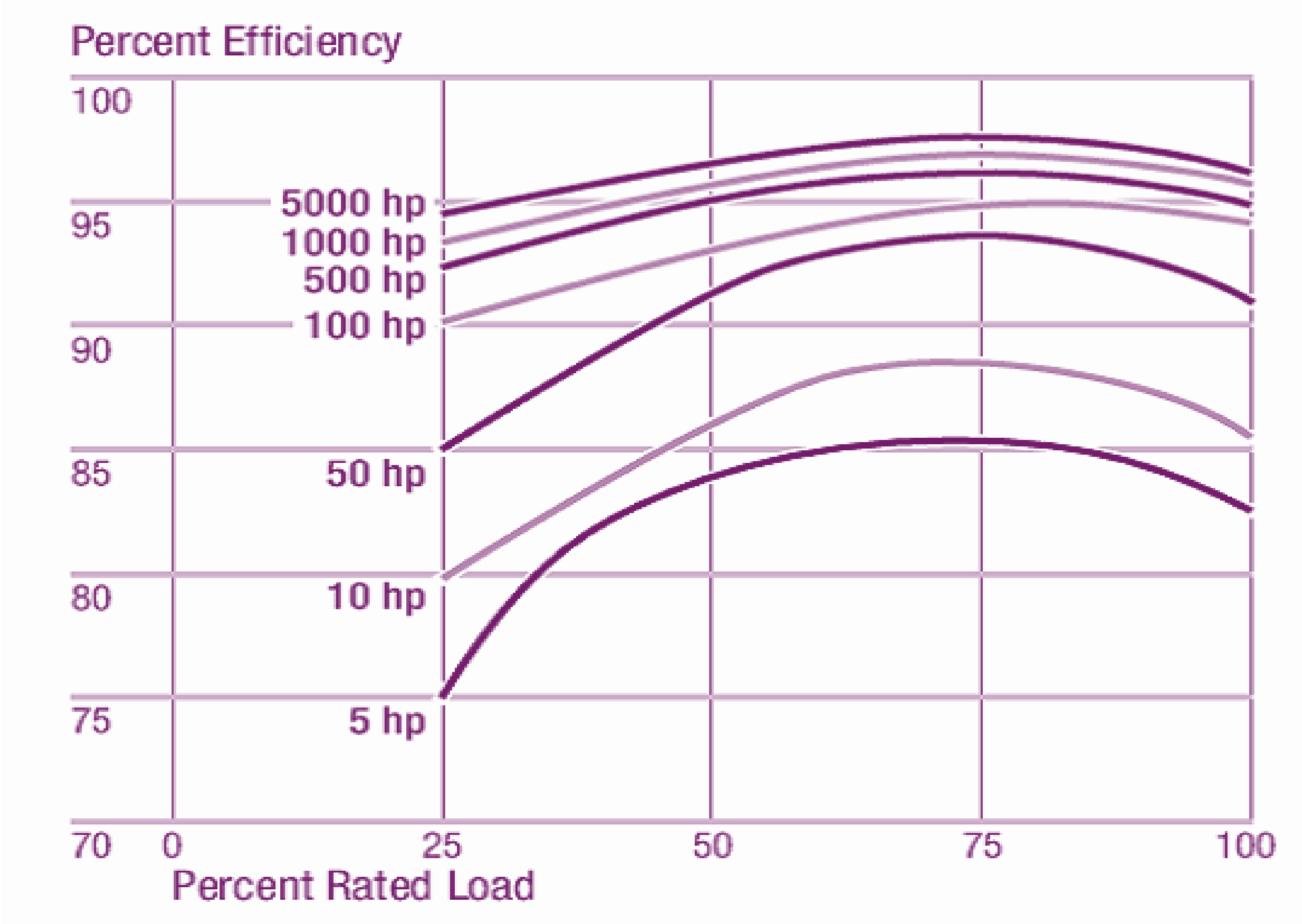
Motor Losses



Efficiency vs. Loading and Power



Factors Affecting the Different Energy Loss Components

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Stator core losses:

- Flux density change
- Excessive radial or axial pressure on core
- Excessive heating during burnout (i.e., damage to inter-laminar insulation)
- Mechanical damage to the core (e.g., splayed lamination teeth, smeared laminations).

Factors Affecting the Different Energy Loss Components

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Stator I2R losses:

- Increased MLT of coils (end turns that are too long)
- Reduced stator conductor cross-sectional area
- Some changes to stator winding configuration.

Factors Affecting the Different Energy Loss Components

Rotor losses:

- Change to end ring cross-section
- Change/damage to rotor
- Machining the rotor
- Flux density change

Factors Affecting the Different Energy Loss Components

Friction and windage losses due to changes of:

- Bearings
- Seals
- Lubrication
- Fan
- Air passages
- Operating temperature

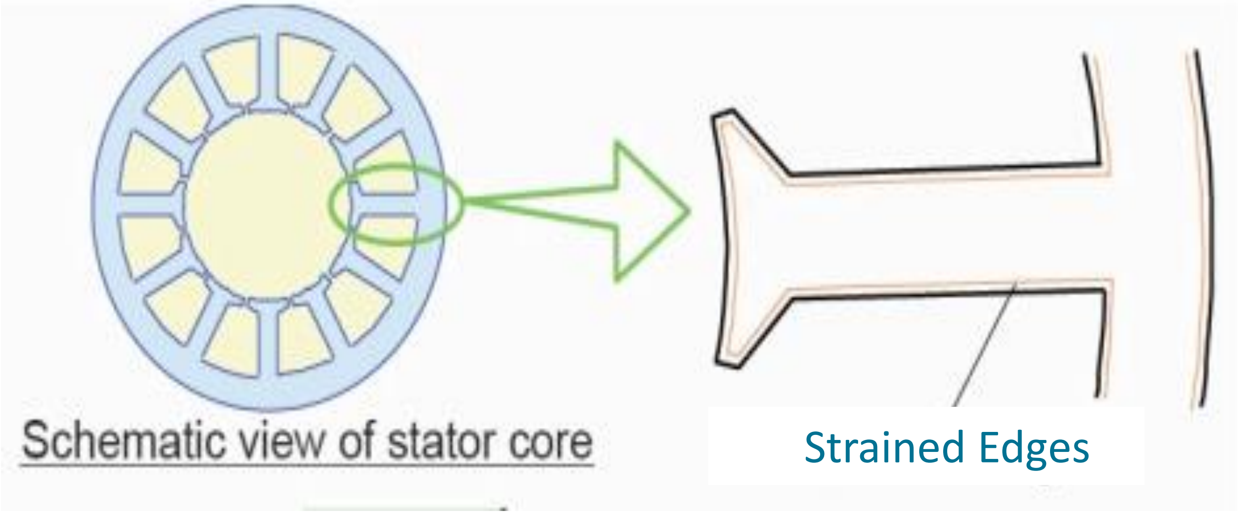
Factors Affecting the Different Energy Loss Components

Stray loss:

- Damage to air gap surfaces
- Uneven air gap (i.e., rotor eccentric concerning stator bore)
- Change in the air gap
- Damage to end laminations

Deterioration of Magnetic Properties due to Punching

The stresses introduced during punching degrade the material properties around the edges of the lamination, and must be removed to obtain maximum performance. This is particularly true for parts with narrow sections, or where very high flux density is required.



Motors Testing

Continuity Testing

By performing a continuity test, we can determine the following:

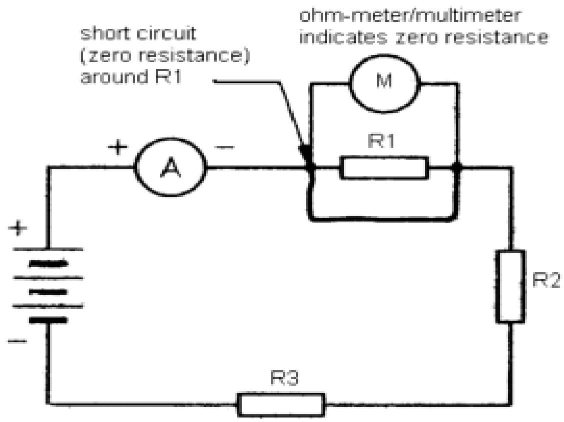
- ✓ existence of continuity in the electrical wiring circuit
- ✓ existence of any open circuit in the circuit
- ✓ existence of any short circuit in the circuit

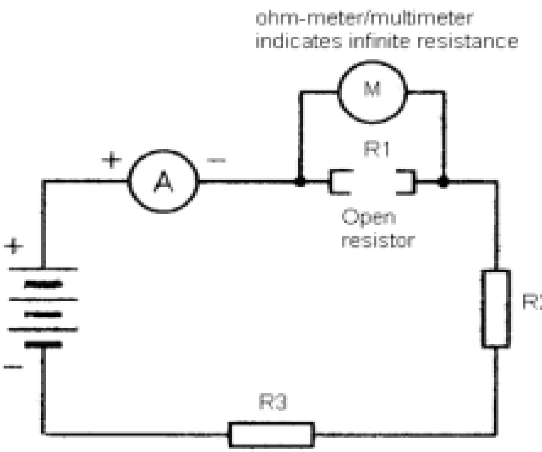
Several devices are available for testing electrical continuity, ranging from multi-meters (AVO) to simple electrical continuity testers that light up if electrical continuity is present.

اختبار الدائرة المفتوحة واختبار دائرة القصر

The AVO-meter must be placed in the resistance measurement mode.

- ✓ Any electrical source in the circuit must be disconnected first .
- ✓ Put both ends of the measurement between the test points in the circuit .
- ✓ If the AVO-meter reads ¦, this indicates an opening in the circuit. If it reads zero ohms it indicates a short circuit.





Motors Winding Testing

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1. Using an Ohm-meter or AVO to measure the resistance between the two terminals of each coil (U → X, V → Y, W → Z). Winding resistance comparison test shall give no more than 5% difference between the winding resistance readings. Otherwise, there is a turn to turn fault in this particular phase or a phase to phase fault. The motor needs rewinding.
2. Repeat the test between each phase and the other 2 phases). The resistances should read infinity. Otherwise, the coils have a phase to phase fault and the motor needs rewinding.
3. Repeat between each phase and the motor frame, the resistances should also be infinity. If you are using a Megger, the resistance should be per the following IEC 60034-2 table. Otherwise, the motor has a phase to ground fault and the motor needs rewinding.

MOTOR RATED VOLTAGE	MEGGER INJECTION VOLTAGE	ACCEPTANCE RESISTANCE VALUE
<1000 V	500 VDC/1 MIN	>5 M OHM
>1000V	1000VDC/1MIN	>100 M OHM

Insulation Testing

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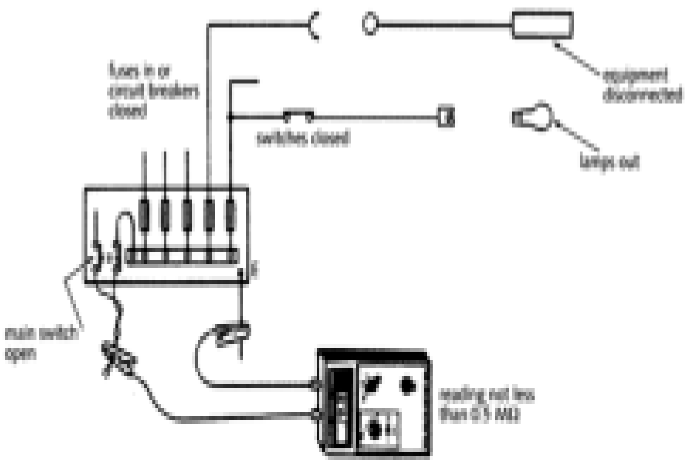
Insufficient insulating can result in leaking current.

- ✓ Leaking current creates heat, which can cause a fire.
- ✓ The current can seep out and flow into another pathway causing short circuit..
- ✓ Leaking current also results in higher electric bills.
- ✓ It can cause ground faults in the workshop or factory and eventually overheat.

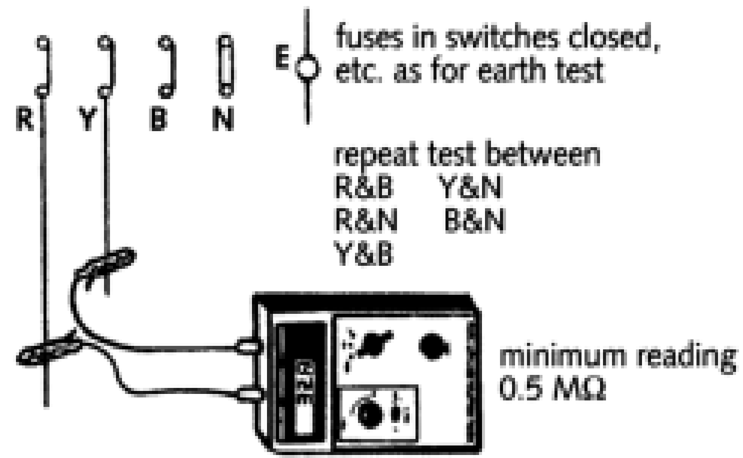
Causes of insulating material deterioration include:

- ❑ Excessive heat
- ❑ Excessive cold
- ❑ Moisture
- ❑ Vibration
- ❑ Dirt
- ❑ Oil

Insulation Tests



Insulation Test to Earth



Insulation Tests Between Phases

Before applying the tester, be sure to disconnect the power from the system being tested. Disconnect all electronics. These can get damaged during the testing process.

Winding Tests

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Measure the resistance of the first coil group wound and compare it with the calculated resistance. If possible, measure the resistance of a coil group from the original winding for comparison. Measure the ambient air temperature (Ta) with the winding at room temperature. Correct both resistances to a convenient common reference temperature (normally 25°C) using the formula:

$$R_x = \left(\frac{234.5 + 25}{234.5 + T_a}\right) \text{ x Measured resistance}$$

Where
Rx = corrected winding resistance
Ta = ambient air temperature

The corrected value of resistance of the new coil group must be equal to or lower than that of the original coil group. When the stator is fully wound, measure and record the resistance of each phase (or between leads) as well as the ambient temperature. Resistance of each should be equal to 5%.

Winding Tests

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Phase balance (or surge comparison) tests:

The test ensures that all three phases are wound and connected in the same way. The test works by applying identical voltage pulses simultaneously to two phases of the winding and recording the voltage decay on a twin beam oscilloscope.

- ✓ Perform on completed winding before impregnation.
- ✓ The test compares the decay rate of identical voltage pulses applied simultaneously for 2 winding phases.
- ✓ Trace pattern indicates phases identical (okay–identical traces) or different (fault–traces do not match).
- ✓ Trace pattern gives guidance to the type of fault.

Winding Tests

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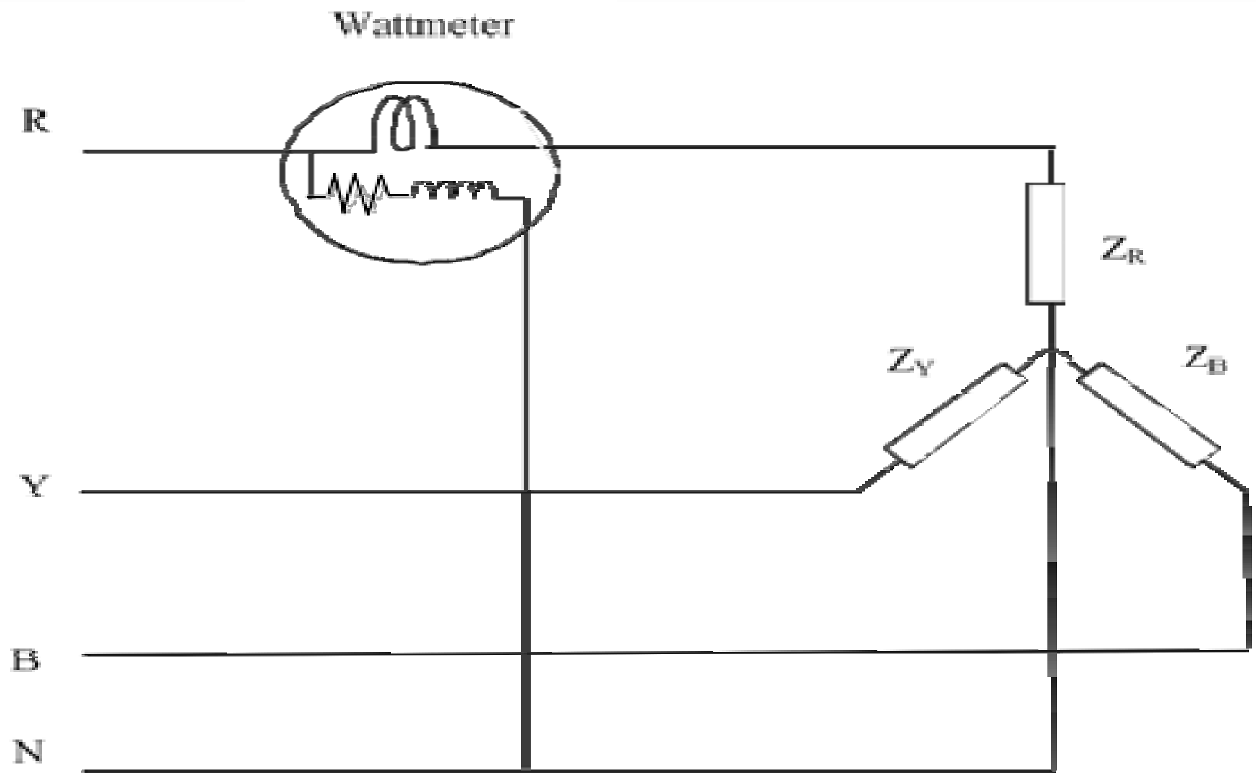
Ground test/hipot (high-potential) test as per IEEE Standard 1068, IEC 60034-2: (For windings rated above 250 volts, larger than 0.5 hp (.37 kW)):

- **AC hipot test voltage: 1000 volts +2 times rated voltage (2000V minimum per IEC)**
- **DC hipot test voltage: 1.7 times the AC test voltage**

The hipot test voltage is intended as a proof test and should not be repeated. If an additional hipot test is required, it should be performed at 85% of the test voltages given above. Subsequent tests should not exceed 65% of the test voltages given above. For old windings, limit the hipot test voltage to 60% of the above test values.

One wattmeter method



Total power = 3 x Wattmeter reading

Measurements of Power

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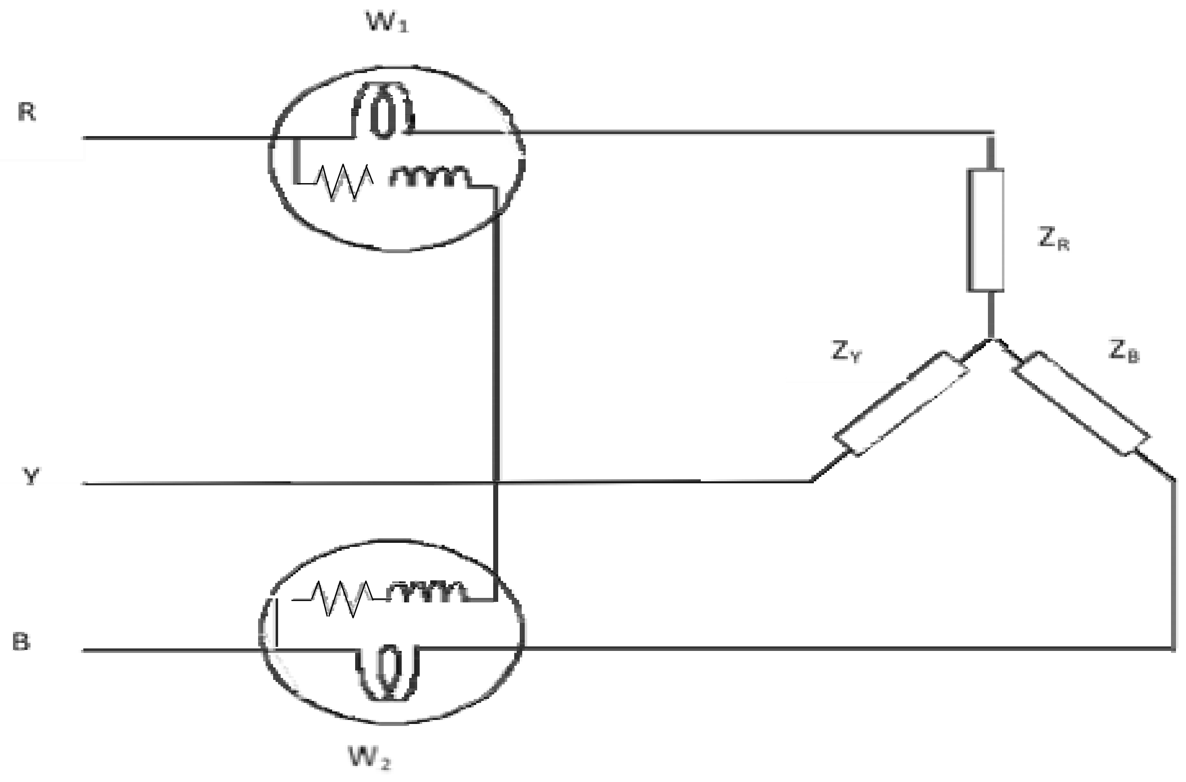
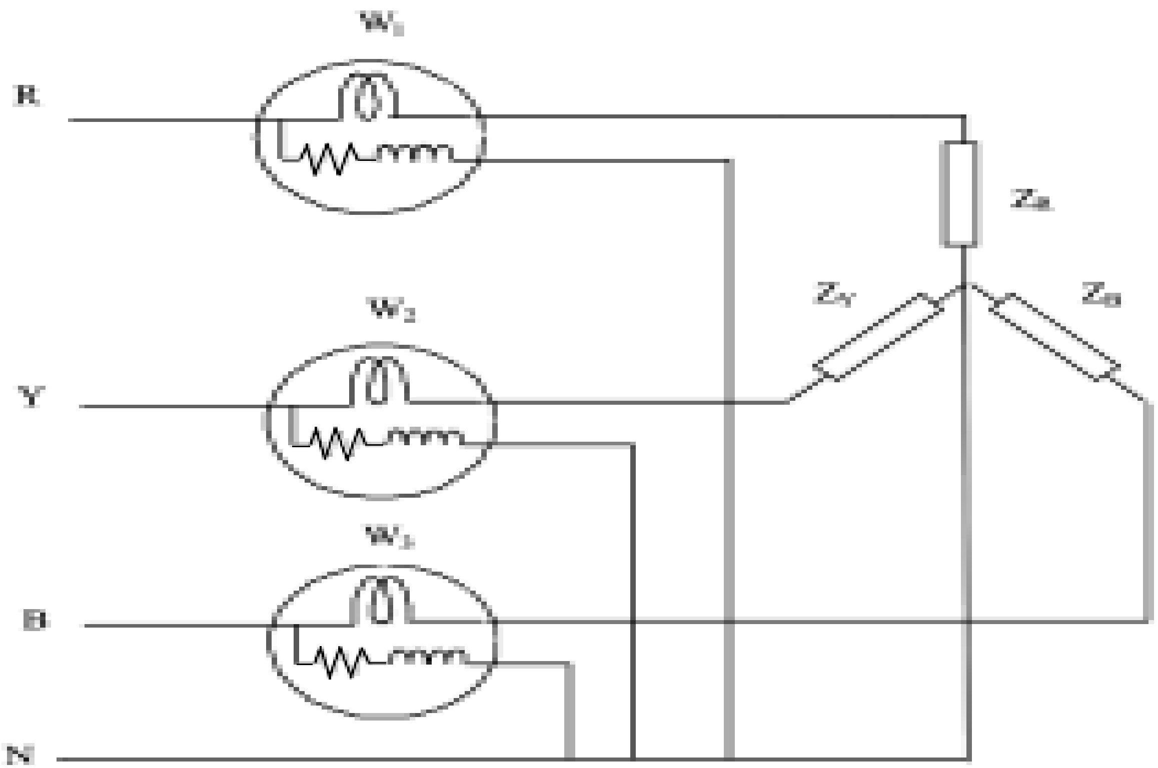
Two-wattmeter method



Total power = W1 + W2

Measurements of Power

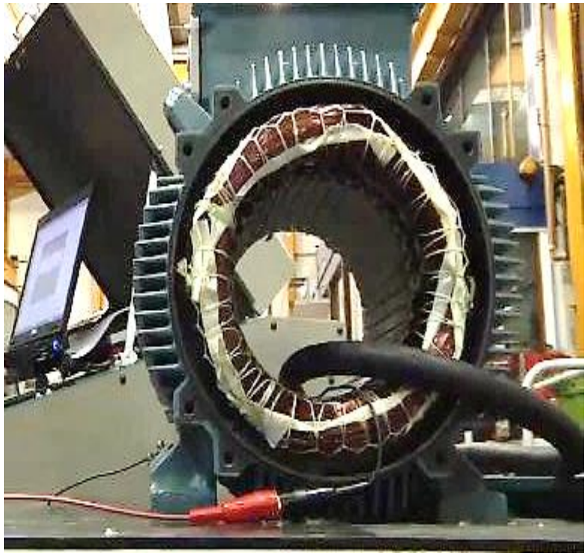
Three-wattmeter method



Total power = W1 + W2+ W3

Core Tests (Loop Test)

- Core test, or core flux test “Loop” test" is the standard test utilized for evaluating the insulation integrity of laminated stator cores. The test establishes a specific magnetizing level for the core by energizing the loop coil with single phase power. Calculations of the number of loop turns required for a desired core magnetizing level are made in a typical target flux range of 85,000 lines per sq. in (85 kl/in² or 1.32 Tesla).
- Any defective areas of the core or tooth insulation will show up as “Hot Spots” in that they will become significantly hotter than the surrounding “normal” areas. (Using infrared thermography ensures accurate results).



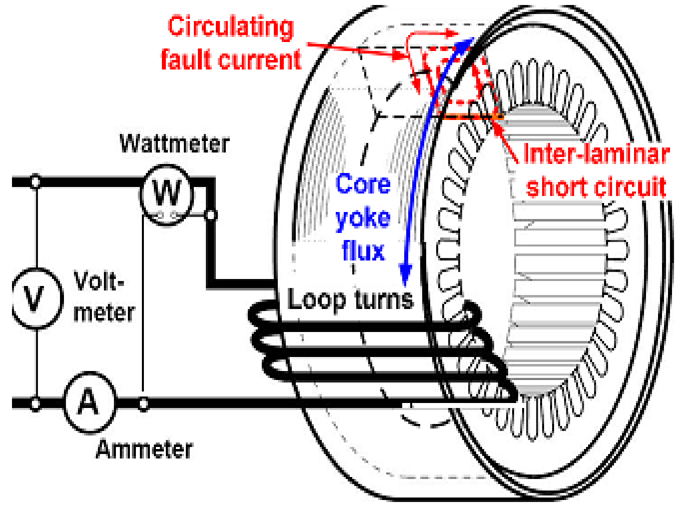
Core Tests (Loop Test)

The loop test is set up by inserting and wrapping turns of lead wire around the core–i.e., passing the leads through the stator bore and around the exterior of the core or stator frame. The core magnetization calculations provide an ampere-turn value that will excite the core to the desired magnetic flux level. The loop turns are typically wrapped close to each other, to maximize the area of the core that can be probed for hot spots.

The measurement is made by inserting a one-turn search coil to detect voltage induced in the core and a true-RMS current transformer to detect the amperage in the loop turns. The voltage and current were then sensed by a wattmeter. The test was performed at the same level of magnetization for both the before winding removal and after winding removal loop tests.

Core Tests (Loop Test)

The core loss value after removing the windings should not exceed that of the before the test by more than 20% (the typical acceptable range of losses is ≤ 8 watts/kg for core weight). To find a hot spot in the core, a higher flux level [from 85 kl/ in2 (1.32T) up to 97 kl/in2 (1.5T)] is recommended.



A complete test of the core may require repeating the loop test with the loop turns placed in a different location to expose the area that is made inaccessible by the initial location of the loop test turns. The core can be probed for hot spots with an infrared thermal detector or thermocouples.

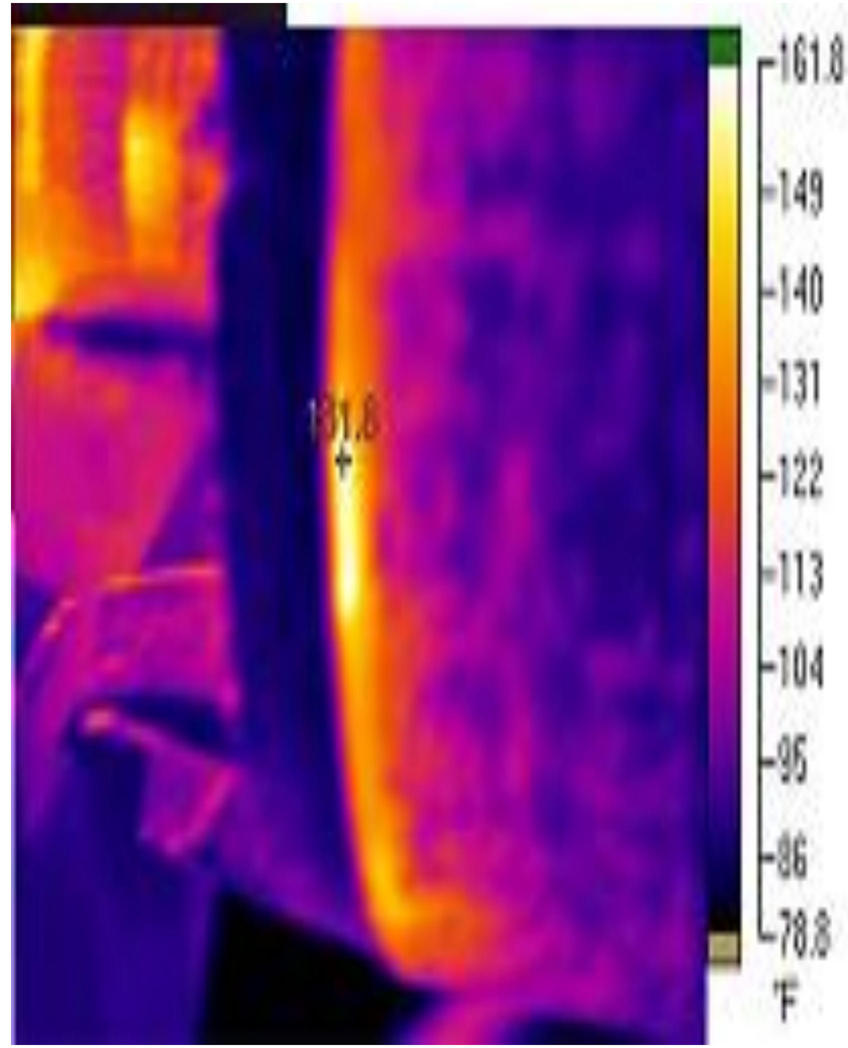
Core Tests (Loop Test)

Commercial Core Testers

Commercial core testers perform core tests that are equivalent in the flux pattern to the loop test. The advantages of using the commercial testers are:

- Save time in performing the test and to improve the repeatability of test results.
- Commercial testers normally require only a single loop turn, because they can produce large amounts of current.
- Testers usually have built-in metering to display current and power. Computer programs typically available from the tester manufacturers can calculate the value of current required to achieve the desired level of magnetic flux, as well as the actual flux level attained during the test.
- The core can be probed for hot spots, just as with the conventional loop test.

Core Tests (Loop Test)



Thank You

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Best Practice Manual in Rewinding Three Phase Induction Motors

This manual is collected, prepared and presented by

Dr. Hany Elghazaly

Cairo University

UNIDO Expert

UNIDO

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Second Day, Rewinding Steps

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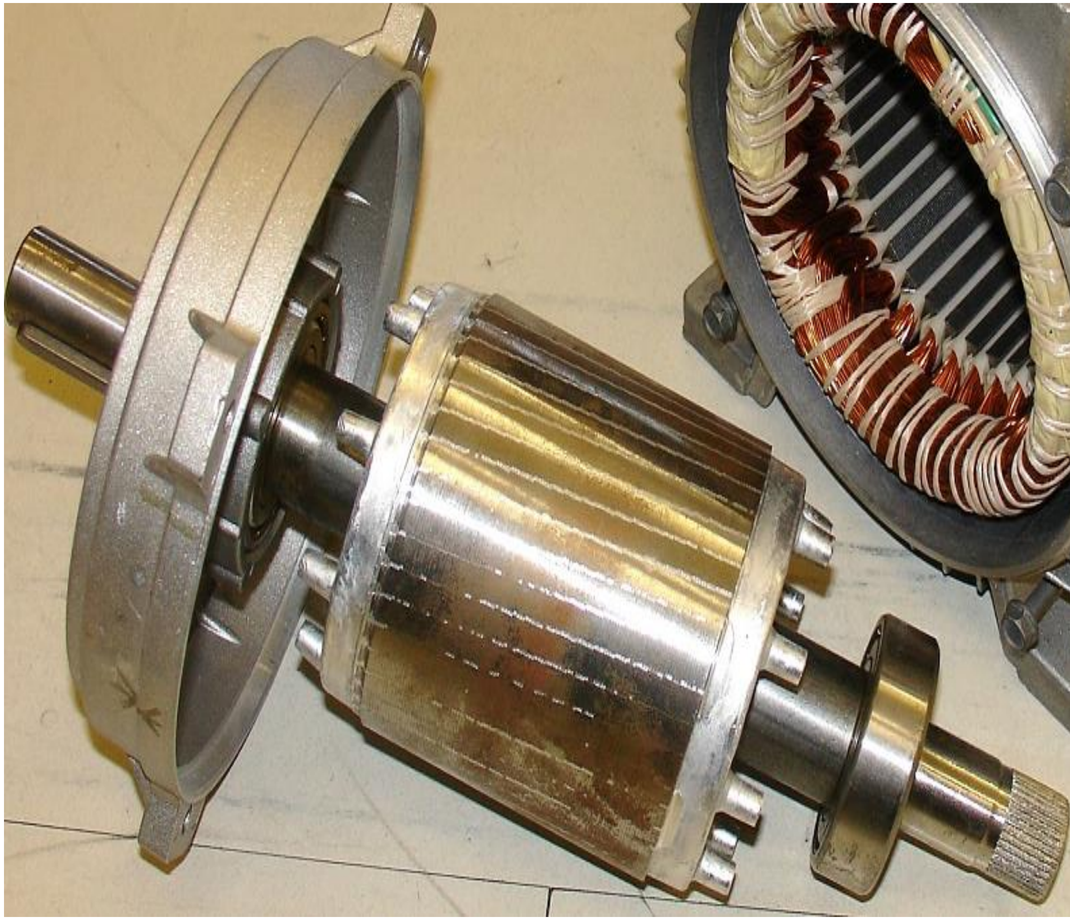
- Checking If The Motor Needs Rewinding
- Gathering Motors Data
- Dismantling the Motor
- Removing the Old Winding and Cleaning the Core
- Rewinding the Motor
- Mechanical Check and Repair
- Reassembling the Motor
- Testing



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Checking If The Motor Needs Rewinding

There can be a wide variety of issues behind motor failures that necessitate rewinding, and most of them make themselves known in the form of failed insulation and/or grounded/shorted coils.

- Insulation failures can take several different forms such as: windings that have shorted turn-to-turn
- windings that have shorted phase-to-phase,
- windings that have shorted coil-to-coil, or
- grounded at the edge of the slot.

Checking If The Motor Needs Rewinding

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Step 1: Inspect the Leads and the Terminal Box

- ✓ Remove the cover of the terminal box and inspect the leads and the taped lead connections for signs of overheating or mechanical damage.
- ✓ In some cases the damage is in the terminal box and fixing may solve the problem.
- ✓ Before measuring remove all connections in the terminal box.

Checking If The Motor Needs Rewinding

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Step 2: Full Test

A full test of the winding condition shall be carried out. Remove the motor terminal box cover and carry out:

1. Winding resistance test and continuity test for each phase coil individually. Measure the resistance between the 2 terminals of each coil using an Ohm-meter or AVO (U → X, V → Y, W → Z). Winding resistance comparison test shall give no more than 5% difference between the winding resistance readings. Otherwise, there is a turn to turn fault in this particular phase or a phase to phase fault is expected and the motor needs rewinding.
2. Repeat the test between each phase and the other 2 phases. The resistances should read infinity. Otherwise, the coils have a phase to phase fault and the motor needs rewinding.

Checking If The Motor Needs Rewinding

3. Repeat between each phase and the motor frame, the resistances should also be infinity. If you are using a Megger, the resistance should be per the following IEC 60034-2, and IEEE Std. 43-2015, Figure 24. Otherwise, the motor has a phase to ground fault and the motor needs rewinding

MOTOR RATED VOLTAGE	MEGGER INJECTION VOLTAGE	ACCEPTANCE RESISTANCE VALUE
<1000 V	500 VDC/1 MIN	>5 M OHM
>1000V	1000VDC/1MIN	>100 M OHM

Injection Voltage and Acceptable Resistance

Gathering Motors Data

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Step 1: General Data

- ✓ Take pictures of the motor's current configuration.
- ✓ Snap a few photos of the outside of the motor from different angles and make a note of the way each of the main components looks.
- ✓ Documenting the motor's appearance before you begin making modifications to it can be helpful in case you make a mistake.
- ✓ Record all the data on the nameplate.

Gathering Motors Data

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Look for and Record:

- ✓ General condition–old/new, dirty/clean, etc.
- ✓ Cooling air ducts clear/obstructed–may have caused overheating.
- ✓ Shaft discoloured (brown/blue)–a sign of rotor overheating or bearing seizure.
- ✓ Parts missing, damaged or previously replaced/repaired–e.g., seals, stator cooling ribs, fan, fan-cover, terminal box, etc…

Gathering Motors Data

Step 2: Rating Plate (Name Plate)

On the motors rating plats, the repairer can find the most useful information about motor. For our needs we find:

- ✓ **Motors nominal voltage (for star (Y) and triangle (D) motor connection) [V]**
- ✓ **Motors nominal current (for star (Y) and triangle (D) motor connection) [A]**
- ✓ **Rated power of the electric motor [W]**
- ✓ **Power factor cos φ**
- ✓ **Rated rotation speed [rpm]**
- ✓ **Nominal frequency [Hz]**
- ✓ **Motor efficiency and efficiency class (IE-)**

Gathering Motors Data

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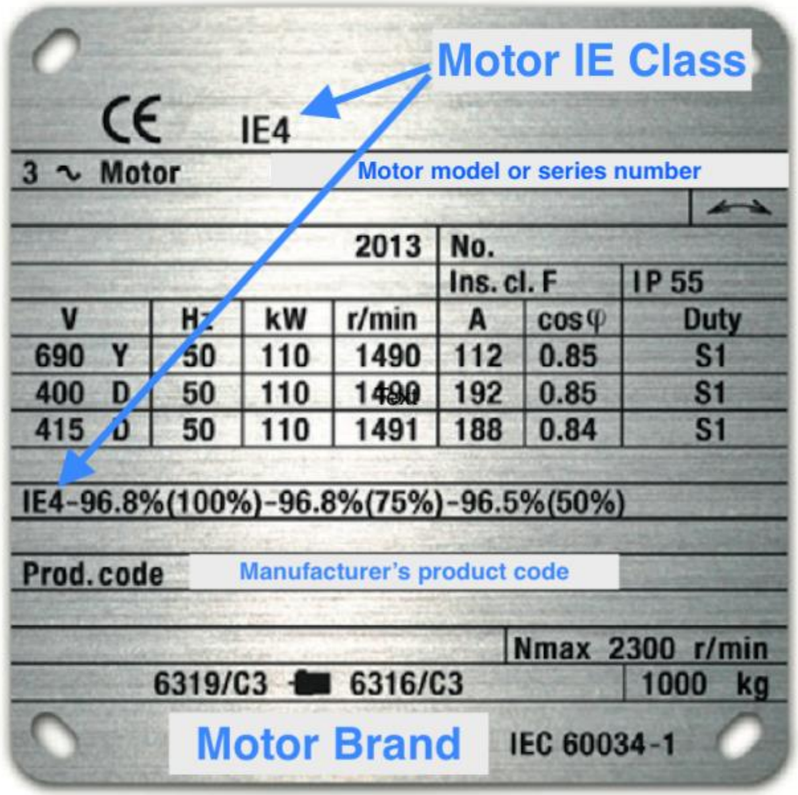
- ✓ **Insulation information, including Insulation class, temperature rise, ambient temperature design base**
- ✓ **Bearing information, such as type, manufacturer and type of used lubricant**
- ✓ **Manufacturer and related data, such as motor style, model, type, as well as serial number**



Rating Plate (Name Plate)

Gathering Motors Data

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Step 3: Customer Input

Customers may be able to provide:

- ✓ **Operating environment–temperature, vibration, etc.**
- ✓ **Type of driven equipment.**
- ✓ **How many hours/day motor run.**
- ✓ **Approximate motor load.**
- ✓ **How often it is started.**

Dismantling the Motor

- It is essential to dismantle the motor carefully and to keep adequate records to ensure that if the motor is repaired it can be reassembled correctly.
- Mark all end brackets and stator frames at both ends of the motor (by punch-marking the components with a centre punch before dismantling the motor.
- Document the mounting position of the shaft to the leads.
- To ensure that you're recreating the original winding pattern and connections precisely, you could even make a video recording of the deconstruction process.
- Place all parts that are not to be repaired in a suitable bin or tray that is labelled with the motor serial number or job card number.

Dismantling the Motor

***Required Records*:**

1. **Terminal box position, layout and connections.**
2. **Orientation of end brackets and bearing caps.**
3. **Bearing sizes, types and clearances.**
4. **The axial position of the rotor relative to the stator (drive end or opposite drive end).**
5. **Orientation of shaft to the main terminal box.**

Dismantling the Motor

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Step 1: Removing Covers

Use an appropriate screwdriver to remove covers from the motor. Usually they are attached to the stator by long screws. If you can't separate cover and stator you can use a rubber hammer. Gently hit the cover and try to rotate.

Dismantling the Motor

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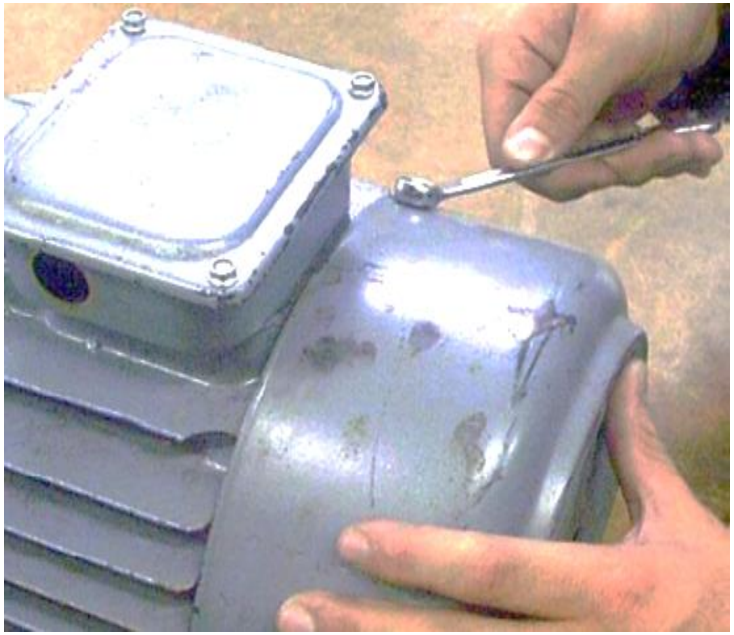
Step 2: Removing the Fan

After removing the fan cover, remove the fan from the rotors axis. Separate it from the axis using a puller. Then remove the second cover.



Dismantling the Motor

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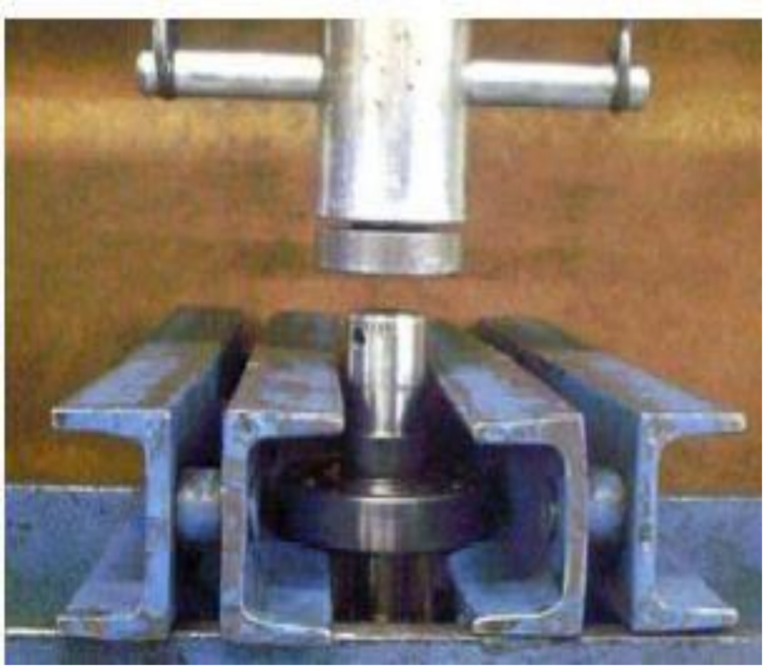
Step 3: Removing the Bearings

Most motors have a ball bearing at each end. Remove the clips with pliers, then remove the front and rear bearings. Use a puller to remove bearings on both sides. You must be careful because you can easily damage the axis of rotor.



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Removing the Bearings

The most common types of tools for removing bearings are two- and three-arm bearing pullers. They range from one- to forty-ton capacity and feature two or three jaws that are slim and tapered, allowing the ends to get easily behind the bearing to its race. For large motors, you may need a hydraulic press.

Dismantling the Motor

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Step 4: Removing Rotor from Stator

It is very important to carefully remove the rotor to prevent damage to air gap surfaces or windings. The rotor presents a considerably load when one end support has been removed. Allowing it to scrape along the stator body during rotor removal can damage the air gap surfaces of both stator and rotor which leads to an increase in losses after winding the motor. Winding damage can also result.

Dismantling the Motor

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Removing Rotor from Stator

- For small motors, you can gently hit the rotors axis with a rubber hammer. You may also Insert a small part of smooth packing materials into the clearance below the rotor and hold the shaft up from the other side while pulling the rotor to make sure that the rotor does not damage the stator during its removal.
- For larger horizontal motors, insert soft smooth packing materials into the clearance between rotor and stator. Place a suitable piece of pipe on the opposite end of the rotor shaft. Take out the rotor from the stator frame. The pipe must be long enough to support the rotor during the shaft is completely glided through the stator opening. You may also need a crane and a largely levelled puller in case large motors

Dismantling the Motor

Removing Rotor from Stator

General Notes:

- ✓ Wear gloves to protect your hands and avoid transferring the oils from your skin to any part of the stator.
- ✓ Be careful not to damage the rotor or any of the surrounding parts of the motor.

- ✓ Once you've removed the stator and rotor, set the frame aside so that it won't accidentally attract stray metal pieces.

Dismantling the Motor

Step 5: Terminal Box Layout and Connections

- Record markings on both winding leads and terminals.
- Record positions of any links between terminals (make a sketch).
- Check that insulation on winding leads immediately adjacent to terminals does not show any signs of overheating (discolouration or brittleness). If it does, replace the leads. Overheating may have been caused by a poor connection.
- Confirm that all terminals are firmly crimped or brazed to winding leads.
- Record size and type of lead wire.
- Record terminals' size and style.

Dismantling the Motor

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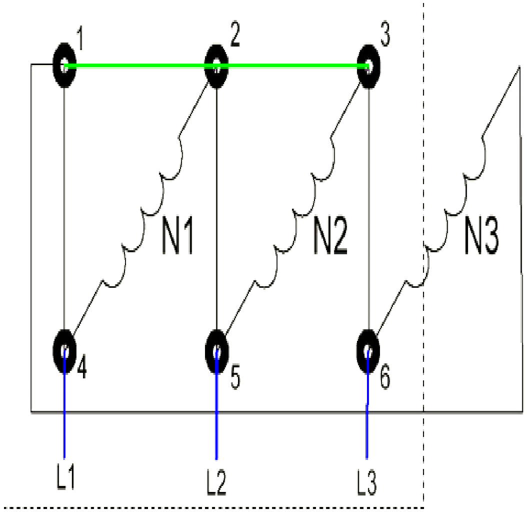
Terminal Box Layout and Connections

Before measuring remove all connections in the terminal box. Repeat the measurements by measuring resistance for each phase coil, resistance between two different phase coils and resistance between phase coils and motors frame.

Resistances of the three windings should be the same (+/- 5%). The resistance between two winding and between a winding to the frame should be as indicated before. You can also detect burned motors winding by its unique smell (smells like burned varnish).



Removing the Old Winding and Cleaning the Core

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There are five elements to this task:

1. Core loss testing
2. Burn-out windings
3. Cut off and extraction of windings
4. Recording the winding details.
5. Cleaning and preparing the stator core for rewinding.

Step 1: Core Loss Testing

- **Although removal of the old winding and cleaning the core are necessarily carried out sequentially, recording the winding details is a coordinated activity carried out, both before and during winding removal. Likewise, core loss testing is carried out at fixed points throughout the process. Follow the core test procedures as explained before.**
- **Commercial core loss testers can indicate whether or not the stator core losses have been increased by the rewind process.**

Removing the Old Winding and Cleaning the Core

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Core Loss Testing

- Core loss testers can be useful provided that the same core tester at the same setting is always used for each test on a given core before and after rewinding. I
- t is also recommended to carry out the core test before burnout and after the core has been cleaned before rewinding. This will give you an indication of quality of how the rewinding process was conducted.
- If the core loss increases by more than 20% (the typical acceptable range of losses is ≤ 8 watts/kg for core weight), repair the core or consider replacing it.

Removing the Old Winding and Cleaning the Core

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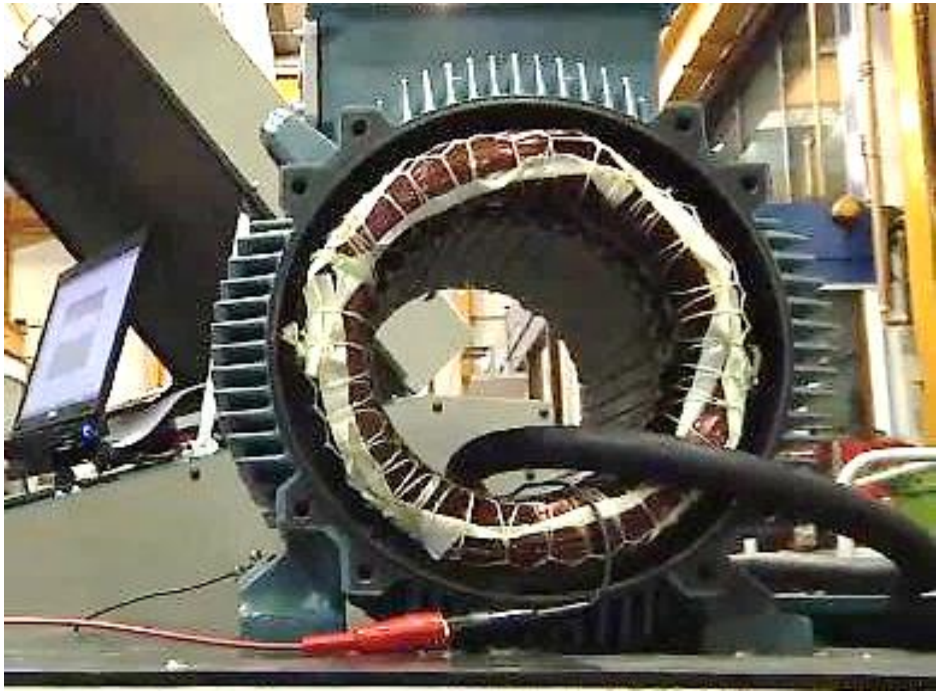
Core Loss Testing



The core loss difference should not increase by more than 20% (the typical acceptable range of losses is ≤ 8 watts/kg for core weight).

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Removing the Old Winding and Cleaning the Core

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Step 2: Burn-out Windings

- The stator core is made of thin steel laminations that are insulated from one another by an oxide coating or an organic or inorganic varnish. This inter-laminar insulation can be damaged if the stator core gets too hot, resulting in increased iron losses and reduced motor efficiency.
- If the stator does not get hot enough to burn out the winding insulation fully, the windings will be difficult to remove. Satisfactory results are achieved with a burnout temperature in the range of 250^{o}C and 350^{o}C depending on the inter-lamination insulation (varnish) used.
- If this temperature is not enough to burn the insulation, increase the oven temperature only up to 370^{o}C if the inter-lamination varnish type permits.

Removing the Old Winding and Cleaning the Core

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Burn-out Windings

- Remove connections and terminal box from the stator. In the next step, you will need to heat old coils, and the terminal box must be empty.
- Heat the core in a burn-off oven to remove hydrocarbon coatings and varnish from slots by ensuring a reduced oxygen atmosphere around the stator. This prevents any possibility of ignition of the coating.
- If you burned old varnish you should be able to push remain winding out of stators gaps.

Removing the Old Winding and Cleaning the Core

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Burn-out Windings

Don't use direct flame in this process. The burn-out oven method is the most tightly controlled of any of the burnout processes. If it is properly done, it ensures that the stator core will not reach a temperature that could damage the inter-laminar insulation.

Burn-out Oven

Removing the Old Winding and Cleaning the Core

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Step 3: Cut Off and Stripping Out Windings

- ✓ **Leave the stator to cool down, then physically remove the windings from the stator core. During this process and after, you need to gather windings data.**
- ✓ **Cut off one coil extension of the winding (usually the opposite connection end) as close to the stator core as possible without damaging the stator's laminations or core.**
- ✓ **Regardless of the method used to cut off the coil extension, be careful not to damage the laminations. You may use a pair of pliers and don't use a hammer and chisels. It may be necessary to cut one wire at a time to make removing the coils more manageable.**

Removing the Old Winding and Cleaning the Core

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Cut Off and Stripping Out Windings

- ✓ **You may also use cut off machine or cut off and extraction machine For large motors you need hydraulic coil cut-off and extraction machine.**
- ✓ **If you have to use a hummer and chisels, Position the chisels to cut the coil extensions in an angle close but not to touch the laminations or frame Do it carefully in order not to damage stators laminations.**
- ✓ **The wedges are lifted using a saw plate and a hammer. By hammering the saw blade until its teeth are embedded in the socket, then pushing by the hammer out.**

Removing the Old Winding and Cleaning the Core

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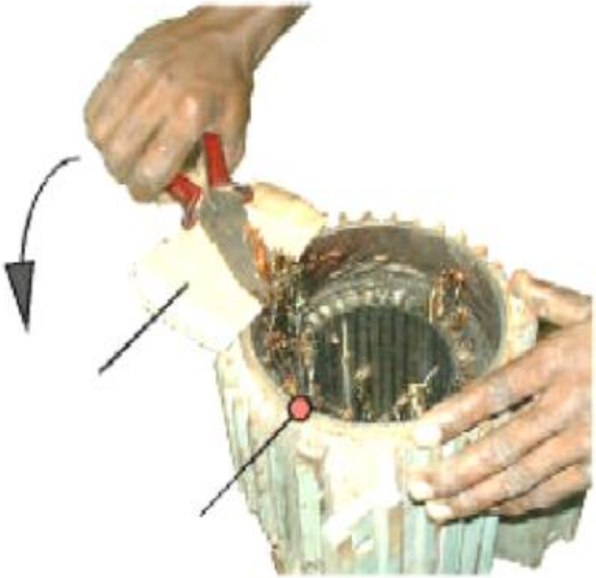
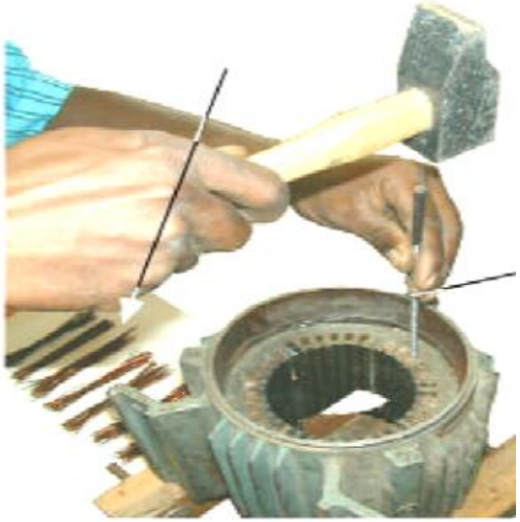
Cut Off and Stripping Out Windings





Manual Cut Off

The wedges are lifted using a saw plate and a hammer. By hammering the saw blade until its teeth are embedded in the socket, then pushing by the hammer out.

Removing the Old Winding and Cleaning the Core

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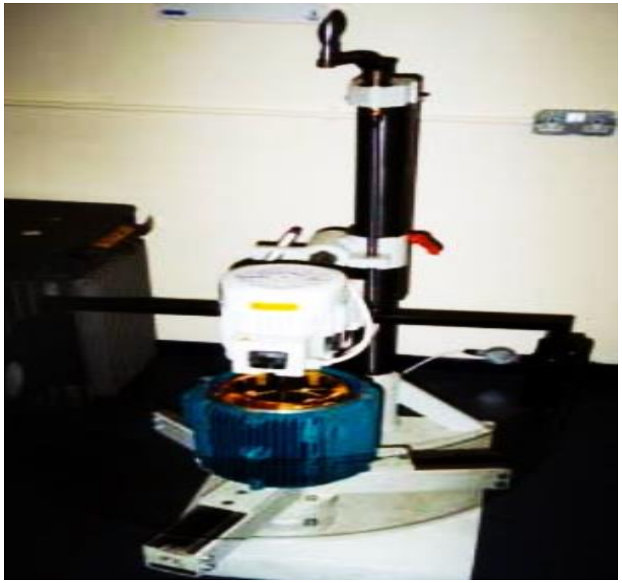
Cut Off and Stripping Out Windings



Cut Off Machines

You may also use cut off machine or cut off and extraction machine as seen in Figure 35. For large motors you need hydraulic coil cut-off and extraction machine.

Removing the Old Winding and Cleaning the Core

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Cut Off and Stripping Out Windings

- ✓ After you cut one coil extension of the old winding from the stator, pull out the old winding taking care not to damage the core (e.g., by spreading the end teeth outwards).
- ✓ If you don't use extraction machine, you may use a puller or use a pair of wire cutters as in the first coil extension.
- ✓ In small motors, you can push the coils by hammering them into the ducts using a solid metal skewer with a diameter less than the duct opening. After the coils come out ,pull out the other way .
- ✓ Be sure to count the number of turns in each coil so that you can rebuild the motor in the exact same configuration.

Removing the Old Winding and Cleaning the Core

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Step 4: Recording the Winding Data

After the motor disassembly, internal inspection and testing of the motor components are very important. All recorded data, notes and test results must be documented carefully. It is important to record the full details of the old winding accurately and permanently. It is also a good idea to save all the winding data gathered over time into your winding database.

Removing the Old Winding and Cleaning the Core

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Recording the Winding Data

You can find all information about the type of old winding in "winding head". The winding head is part of winding where all connections are made (front side). By the winding head or from the collected wires in each slot in step 3, type of winding, the number of wires in each slot and thickness of the wire, rewinding of the coil can be achieved without doing any calculation or redesign

Burned Winding Head

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Recording the Winding Data

Document the appropriate fields to ensure that the winder can duplicate the winding, and the engineer can confirm its suitability. This data is used to replicate the original motor. The data you need may include:

- ✓ Winding configuration (lap, concentric, single, two or three layers, etc.)
- ✓ Number and size of wires in each coil *with and without varnish*
- ✓ Number of slots
- ✓ Number of poles
- ✓ Number of phases
- ✓ Number, size and marking of leadsTurns/coil
- ✓ Grouping
- ✓ Coil pitch
- ✓ Connections
- ✓ Weight of a single coil and weight of total winding
- ✓ Front and rear end bearing numbers and types

Removing the Old Winding and Cleaning the Core

Recording the Winding Data

External Data					
Power	kW		Volt	V	
Speed	RPM		Current	A	
Frequency	Hz		No of Phases		
Connection	Y/Δ		Number of Poles		
Internal Data					
Number of Coils			Total Number of Slots		
Number of Coils per Slot			Number of Coils per Group		
Wire Diameter w/without Insulation			Number of Turns/Coil		
Coil Pitch			Type of coil - Connection		

Example of a Data Collection Sheet

Removing the Old Winding and Cleaning the Core

Recording the Winding Data

The repairer should carefully inspect the windings and try to determine the cause of failure. A winding that is evenly discolored at both ends may indicate a failure due to a ventilation problem, overload or low voltage. Check the load conditions with the customer; a motor with greater power may be needed for the application. In that case, rewinding the old motor may result in another failure due to overload, possibly within the guarantee period offered by the repairer.

Removing the Old Winding and Cleaning the Core

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Recording the Winding Data

Complete visual inspection is also very important to record any symptoms of:

- Condition of stator and rotor cores–damage.
- Condition of winding–discoloration or overheating of cores and type of failure.
- Core rub, often due to failure of one of the motor bearings or rotor pullover caused by excessive radial loads.
- Major mechanical damage to either the stator or rotor cores.

Certain damages to the stator or rotor may need changing the damaged part and not rewinding it.

Removing the Old Winding and Cleaning the Core

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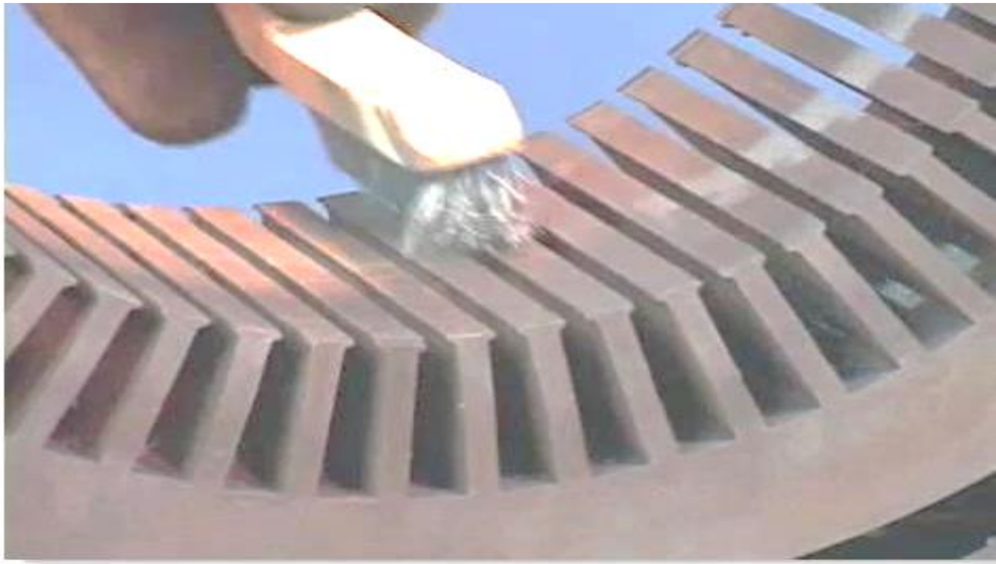
Step 5; Cleaning and Preparing the Stator Core for Rewinding

After the old winding has been removed from the core, slot insulation and other debris may remain in the slots. This must be removed carefully to avoid damaging the core. Satisfactory methods for cleaning stator slots include careful scraping with a sharp knife, high-pressure washing, blasting with a mildly abrasive material, brushing with a medium/soft wire brush.



Cleaning the Stator Core

Removing the Old Winding and Cleaning the Core

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Cleaning and Preparing the Stator Core for Rewinding

Perform sandblasting which is the process where fine sand hits the surface of the work-piece with very high speed and slightly remove any particles or paint from it. You can also use very fine sandpaper. You can easily remove the old colour from the motor with sandblasting. While sandblasting you need to be careful, that you don't damage the surface too much, especially edges of slots and laminations.

Sandblasting

Removing the Old Winding and Cleaning the Core

Cleaning and Preparing the Stator Core for Rewinding

Paint the external surface of the stator using a paintbrush or spray. The paint must withstand at least 100 degrees Celsius. Make sure you don't paint the label board (nameplate).

Painting

Mechanical Check and Repair

After cleaning the slots, reposition damaged teeth, repair minor damage to air gap surfaces. If you don't have enough experience or tools, send the damaged parts to special shops to replace or reinsulate and rebuild cores or if major damage to the stator or rotor has occurred.

Damaged Teeth at the End of the Core

Sometimes teeth on the end laminations will be disturbed when the coils are removed. It is important not to hammer them excessively to get them back into position. The use of a soft-faced hammer with minimum force is recommended.

Damage to Air Gap Surfaces of Core

The air gap surfaces of the stator and/or rotor cores may have been damaged. The most common damage results in the laminations being smeared together. If the damaged area is not extensive, the effect on losses and efficiency should not be significant. In cases of relatively minor damage, bumping the affected area axially will usually improve things. If this does not work, use a sharp knife to separate the laminations in the damaged area and treat them with insulating material of an appropriate temperature rating. Insulating varnish may also seep between the separated laminations when the new winding is impregnated, helping to restore the inter-laminar insulation.

Replace or Reinsulate and Rebuild Cores

If the damaged area of the core is excessive, there is a risk that losses will have been increased significantly and that motor efficiency will be sharply reduced. The best solution in such cases is to replace the core, or to dismantle, reinsulate and rebuild it if you have such experience and tools.

Rewinding the Motor

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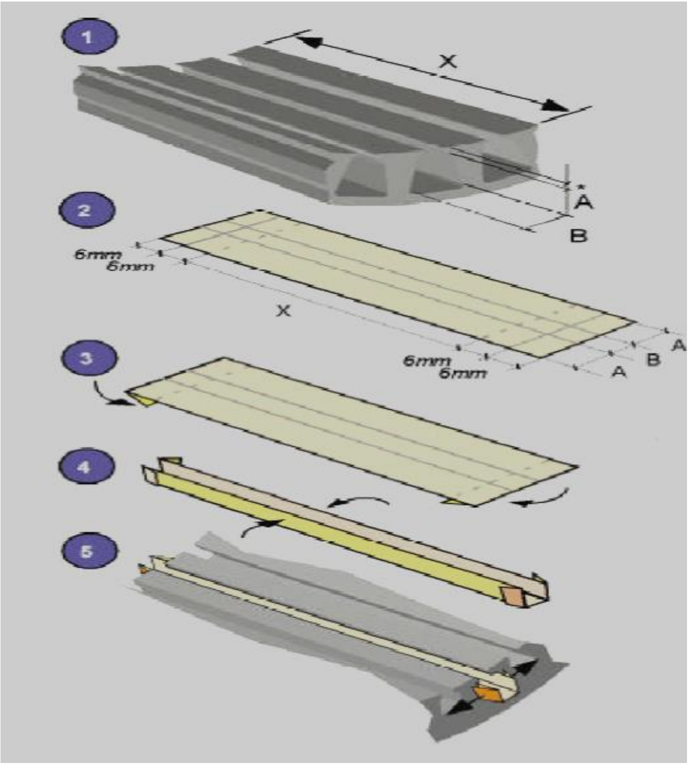
Step 1: Isolating Stators Slots

- Pull the old paper out of the slots in the stator using a pair of pliers or tweezers.
- Measure the length of the slot, and add about 12 – 16 mm .
- Put the isolating paper on a table. Cut it and twist it as shown in Figure, so that A is less than the slot height by 2-3 mm.
- Insert isolating paper in the slot and then twist it. Use a screwdriver to bend it and insert it in the slot gap. It should fit perfectly so you can't pull it out



Do not, under any circumstances, attach the new wire directly to the bare steel stator. The slots must be insulated at all times in addition to the wires' insulation.

Rewinding the Motor

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Isolating Stators Slots

- ✓ Do not extend the slot insulation beyond the slot ends any more than is necessary to prevent strain on the slot cell.
- ✓ Do not extend the straight portions of the coil sides any farther than is necessary to clear the slot insulation.

Rewinding the Motor

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Step 2: Winding Coils

- Winding the coils is done after taking the required information and after removing the old coils. This is done according to the number of groups and coils, the type of winding and the diameter of the wire. An appropriate form is made with the size of the winding pitch.
- The process begins with knowing the type of winding. If the winding is concentrated, a piece of thick wire is formed in the shape of the inner slots of the first small coil with an increase in length about one and a half centimeters outside the slot length on each side and increases as the motor capacity increases.

Rewinding the Motor

Winding Coils

- You must not leave too much space, because winding would be too little, and you must not make it too small, because you will not be able to access all slots.
- Then the process is repeated for the next coil, provided that it extends outside the slot length from the two sides, so that the distance between it and the first coil is approximately one centimeter. Similarly, more than one coil can be obtained. This process is known as taking a step shot or making a coil model.
- Rewind the stator using the same size of wire. The wire in the new coils must be the same thickness and have the same number of turns as the original windings. Otherwise, it may be a poor fit or increase the winding copper losses.

Rewinding the Motor

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Winding Coils

- Our next step is the actual making of the coils. Key parameters of this process include layering, wire tension, and keeping count of the number of turns on the coil. Please keep in mind that the process varies when you are making random wound coils versus form wound coils.
- Random wound coils are made in a repair shop using rollers of magnet wire and winding heads to make the correct length coil. Form coils are made by a manufacturer that specializes in form coils and has the correct wire, tapes, press equipment, spreading equipment, testing capabilities, etc.

Rewinding the Motor

Winding Coils

- Use a winding tool. Make sure you wind the correct number of turns. After you wind coil you need to tie it up with Magnet Wire tape string or plastic ties for securing the conductors of the finished coils. Then you can take it off the winding tool.
- Keep the coil extensions within the measured dimensions of the original winding. Reducing the length of the coil extension will reduce the amount of copper in the winding and reduce losses. If taken too far, however, this principle can make winding a stator difficult or even impossible.

Rewinding the Motor

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Coil Winding Machines

Automatic

Semi-Automatic

Manual

Rewinding the Motor

Step 3: Inserting Coils in Stators Slots

- Make sure that the ends of the coils are at the side with the hole of the connection box.
- The coil is held by hands from both sides of the core and the turns of the first side of the coil are divided into groups and then each group is pushed after the other until it settles at the bottom of the slots .
- Be careful not to damage the wire varnish. Follow the same method when dropping the second side of the coil.

Rewinding the Motor

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Inserting Coils in Stators Slots

- After the completion of dropping all turns, a wedge or a cover of Persian paper (Press Pan) is placed on top in order to prevent the wires from coming out of the slots.
- Follow the same procedure with the rest of the group coils and all motor coils. Making sure that there are no wires behind the slot insulation. Take into account the preservation of the wires from any scratches or friction with the slot iron.
- Make sure to mark the ends of the coils at the time you are inserting.

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Inserting Coils in Stators Slots

Mark the Ends of the Coils

Inserting Coils

Inserting Coils in Stators Slots

- You can use tamping tools (manual coil inserting tools) to compress the bottom coils in the slots making it easier to insert the top coils. They must be free of burrs to prevent scratched, wires and cut slot, liners. Tamping tools are available in several widths. A tamping tool that is too wide may damage the slot liner, in a place where it is difficult to notice, that could shorten the life of the winding.
- If the Press Pan insulation used is not smooth enough, use scuff paper or feeding paper. It consists simply of two pieces of smooth insulation. Its purpose is to help the winders slip the wires of the coils into the slots more easily. It also keeps the magnet wire insulation from being scratched from insertion.

Rewinding the Motor

Inserting Coils in Stators Slots

Recreate the original winding pattern for each group of coils. The exact configuration you use will depend on the specific type of motor you're repairing. To ensure optimal performance, take great care to make each coil tight, precise, and compact, without any unnecessary crimping or spacing.

- ✓ Always, leave the end of your first winding free and make sure it's long enough to reach the terminal box or the other coils' ends.

Rewinding the Motor

Inserting Coils in Stators Slots

- ✓ Unless you're familiar with the old winding pattern, don't try rewinding it since the motor may not work correctly if you make a mistake.
- ✓ Double-layer windings distribute flux through the core better than single-layer windings. Replacing a double-layer winding with a single-layer winding will certainly reduce motor efficiency, so it is not recommended.
- ✓ It is preferable that lap windings be short-pitched (i.e., the coil pitch must be less than the pole pitch unless the winding has only one coil per group).

Rewinding the Motor

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Step 4: Connecting Coils

- After fully inserting the winding, connect the coils and leads to match the original connections exactly. Use connection leads that are as large as practical and mark all of them correctly.
- Wire coils together according to the winding diagram. Soldering or welding then isolating them are of great importance. End of each coil wire to the terminals box and extra isolate them. Always use isolating sleeves to insulate the connections.
- When inserting the 3 phase coils are completed then, you must connect the coils to form the three complete winding groups with 6 terminals.

Rewinding the Motor

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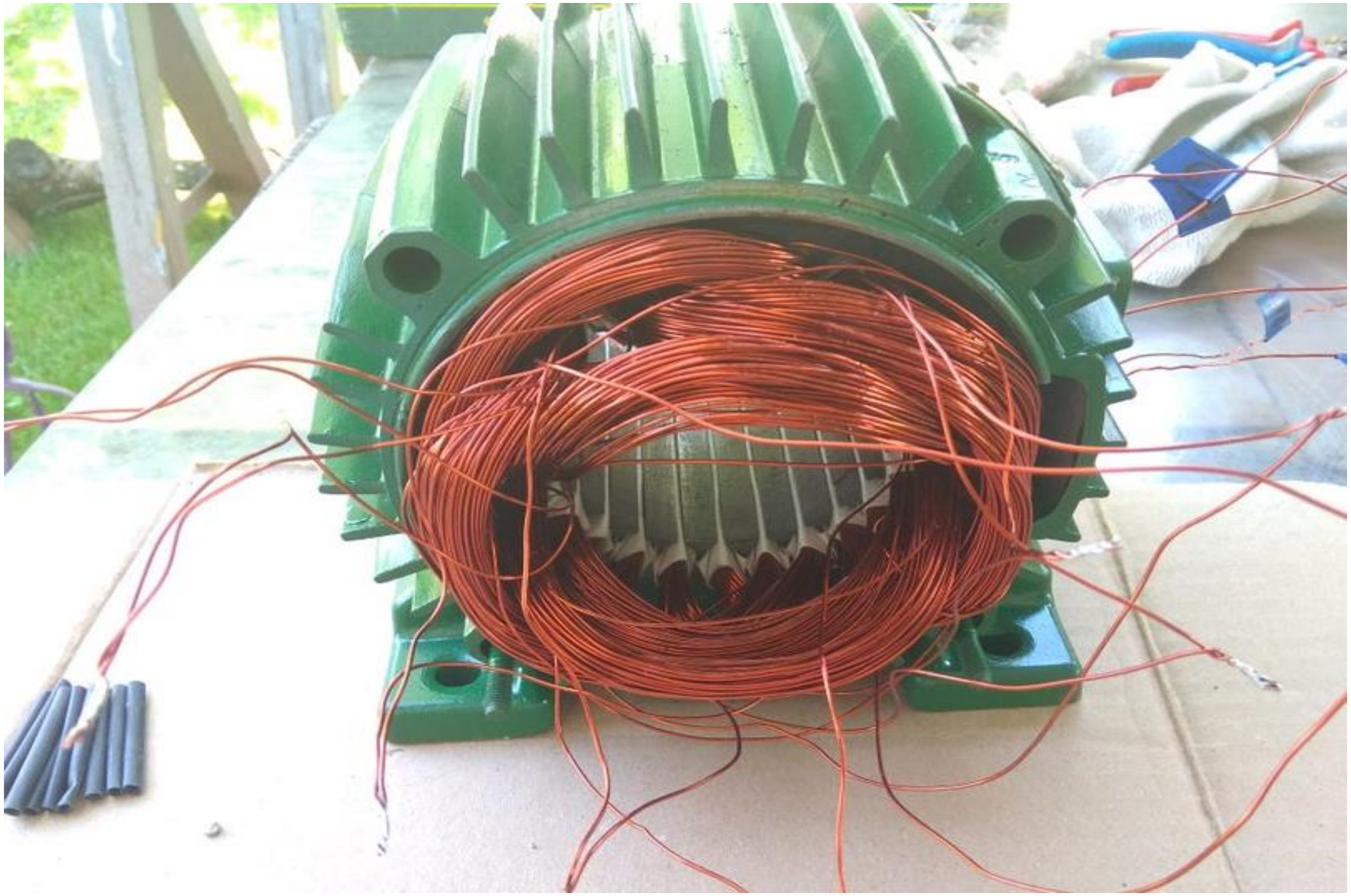
Step 4: Connecting Coils



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Rewinding the Motor

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Step 5: Bind the Coils (Lacing and Bracing)

- The lacing and bracing of the winding are important factors to note in this process. If a winding is not braced properly, the mechanical movement can cause winding failure.
- Brace the coil extension either as the manufacturer's original winding or better (i.e., more rigid).
- Bind the coils with the stator lacing thread. Stitch stator lancing thread around coils. Tight winding well as seen on pictures.

Rewinding the Motor

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Bind the Coils (Lacing and Bracing)

- Secure completed windings using the tabs around the stator. Every time you finish a section, lower the tabs down over the coils. This will help hold them in place while you work and ensure a proper connection once the motor is operational.
- In some cases, you can remove a small amount of insulation paper from the spot where the wire makes contact with the tab using a sharp knife or sandpaper to improve the connection.
- Perform winding resistance, insulation resistance, phase balance and voltage withstand tests as described in the testing section.

Rewinding the Motor

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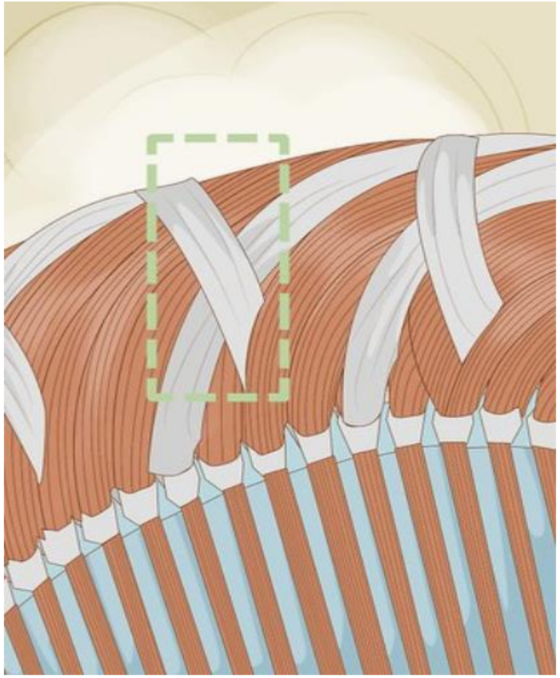
Bind the Coils (Lacing and Bracing)



Rewinding the Motor

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Step 6: Varnishing the Motor

- Besides providing electrical insulation, the varnish used also keeps the coils from moving, bonds the multiple coils together, and protects the windings from contamination.
- One of two approaches can be used for applying the insulation to the newly wound coils: the more traditional varnish dip and bake or the technologically advanced vacuum pressure impregnation process (VPI).
- Varnish dip sometimes called varnishing or "dip and bake," involves warming the new winding, dipping it in a container of varnish (this could be water-based or epoxy-based). Then heat it in an oven to fully cure the varnish or resin. This is the traditional method for repair shops after a rewind is complete.
- The traditional varnish dip is also used when a motor is reconditioned. However, on new motors, a simple varnish dip should be replaced by Vacuum Pressure Impregnation.

Rewinding the Motor

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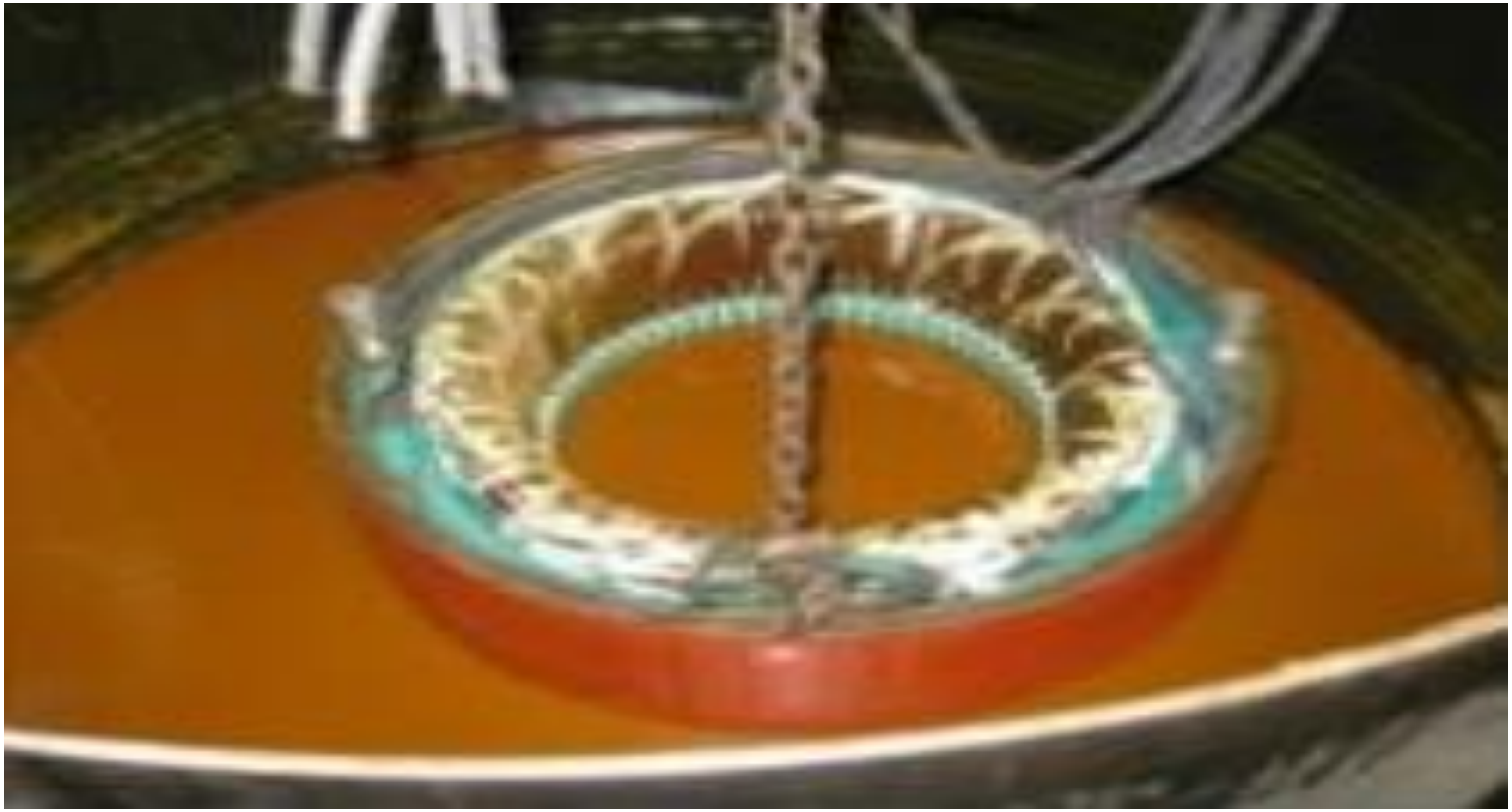
Varnishing the Motor



Dip and Bake

Rewinding the Motor

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Vacuum Pressure Impregnation

With VPI, highly controlled vacuum and pressure cycles are used to penetrate and coat the windings with multi- layers to build solvent-less epoxy resin. The reason why it is replacing the more traditional varnish approach lies in the advantages it provides such as providing superior performance in harsh environments. It also increases efficiency through better heat transfer, is less susceptible to contamination, and reduces coil vibration.

Rewinding the Motor

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Vacuum Pressure Impregnation

1. Heat up curing oven to 100 °C. Put the motor in it.
2. When the motor heats up, spill varnish on the motor's coils.
3. Turn motor around and do the same
4. You can reuse old varnish.
5. Put the motor in a hot oven, and cook it for about 4 – 6 hours.
6. Take motor out and clean edge (so the cover will fit perfectly).

Reassembling the Motor

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Step 1: Reattach Bearings

- To re-attach the bearings lubricate of rotor axis then use hydraulic press or a steel tube of the same diameter of the bearings and a hummer.
- If you need to change the bearings, replace it with the same model and size. You may find the type and size of the old bearing on its side. If you can't find it, you can measure it and find matching model number in catalogue on internet.

Reassembling the Motor

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Step 2: Attach Cover

Attach the cover on the stator. Watch marks to put the cover into right place.

Reassembling the Motor

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Step 3: Putting the Rotor into Stator

Put the rotor in the stator, and close it with the second cover. Screw motor together. You may use different techniques or tools for large motors.

Reassembling the Motor

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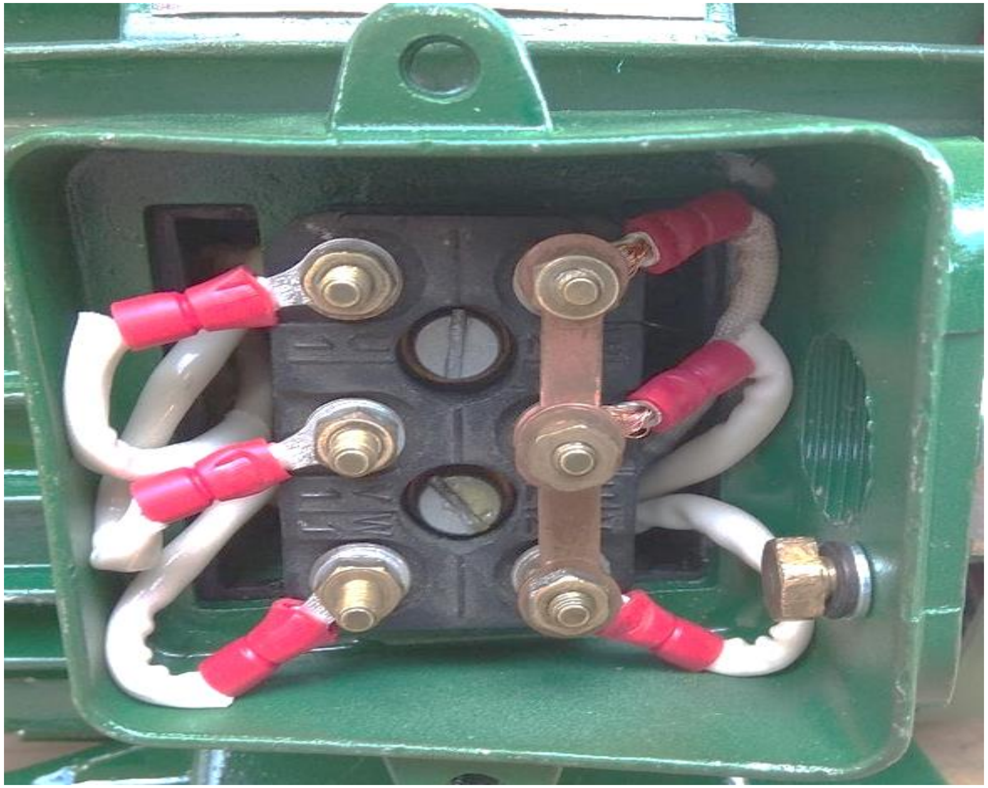
Step 4: Connect End of Coils to Clips in the Terminal Box

Connect the end of the coils to clips, according to the data you collected before.



Reassembling the Motor

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Step 5: Reassemble Fan and Fan Cover

Put the fan and the other cover on motor. If you have iron fan you may need to heat it.

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Motor Testing

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To perform full tests to determine the motor efficiency and the other characteristics according to the international standards, mount motor on the laboratory special test bench, and connect it with measurement equipment. Some of these tests are carried out in the factory laboratories but not in a workshop. The main tests required are:

- ✓ Resistance of winding
- ✓ Free running test of an electric motor
- ✓ Test of the loaded electric motor
- ✓ Optimal voltage test
- ✓ Short circuit test
- ✓ Torque characteristics

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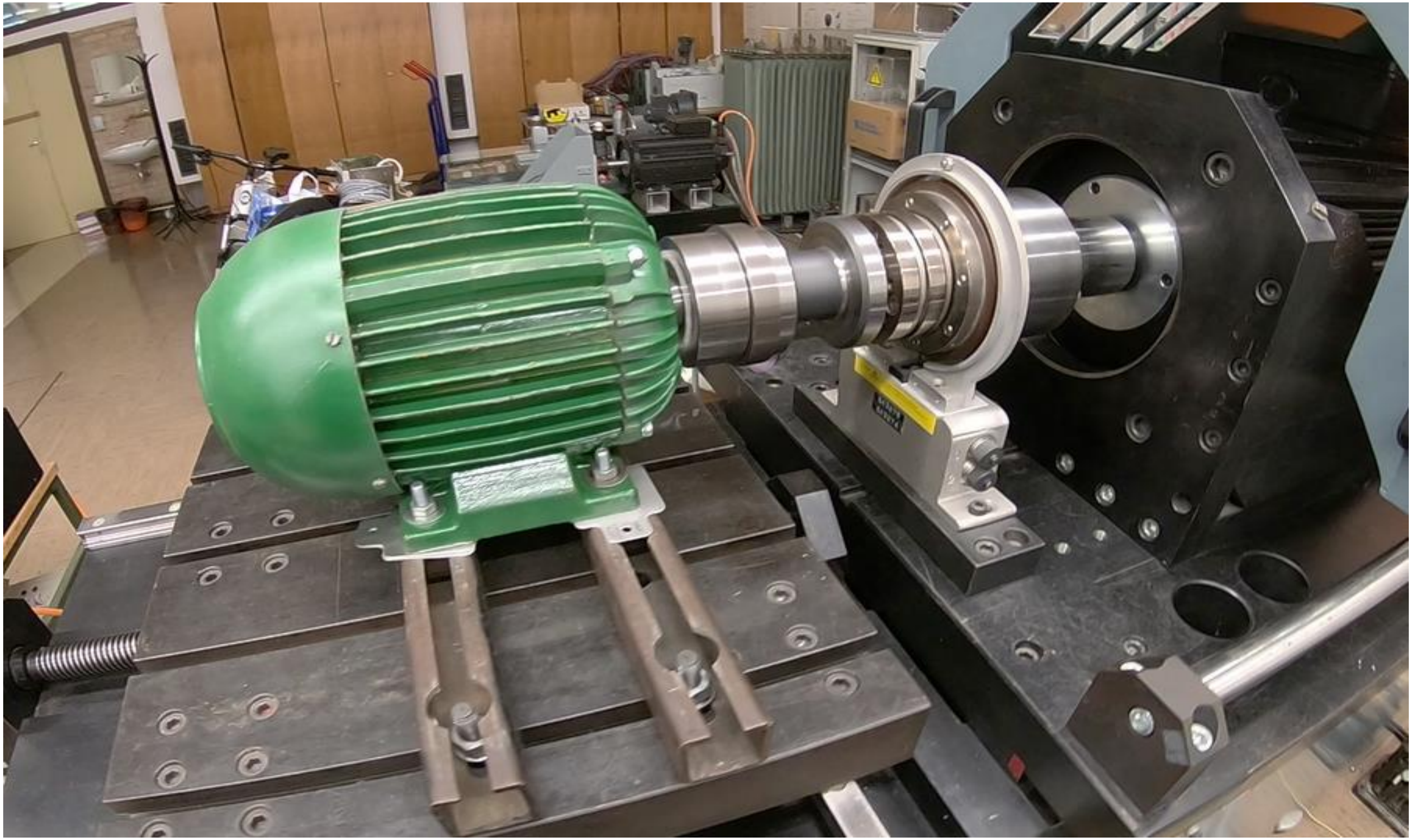
Motor Testing



Motor Testing

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Free run motor test

U [V]	I [A]	P_{in} [W]	PF	P_{cu} [W]	P_{fe} [W]	P_{frw} [W]
380,0	1,18	160	0,206	18,9	34,2	106,9
400,0	1,33	1,68	0,183	23,9	37,7	106,9

Optimal voltage test

U (V)	I (A)	P_{in} (W)	PF	M (Nm)	n (1/min)	P (W)	EFF	P_{loss} (W)
440,3	2,99	1853	0,812	5,05	2833,1	1499,7	0,809	353,7

Loaded motor test

U (V)	I (A)	P_{in} (W)	PF	M (Nm)	n (1/min)	P (W)	EFF	P_{loss} (W)
379,9	3,31	1996	0,903	5,3	2700,9	1500	0,763	465,7
399,9	3,1	1892	0,88	5,18	2763,5	1500	0,793	392,1

Motor Testing

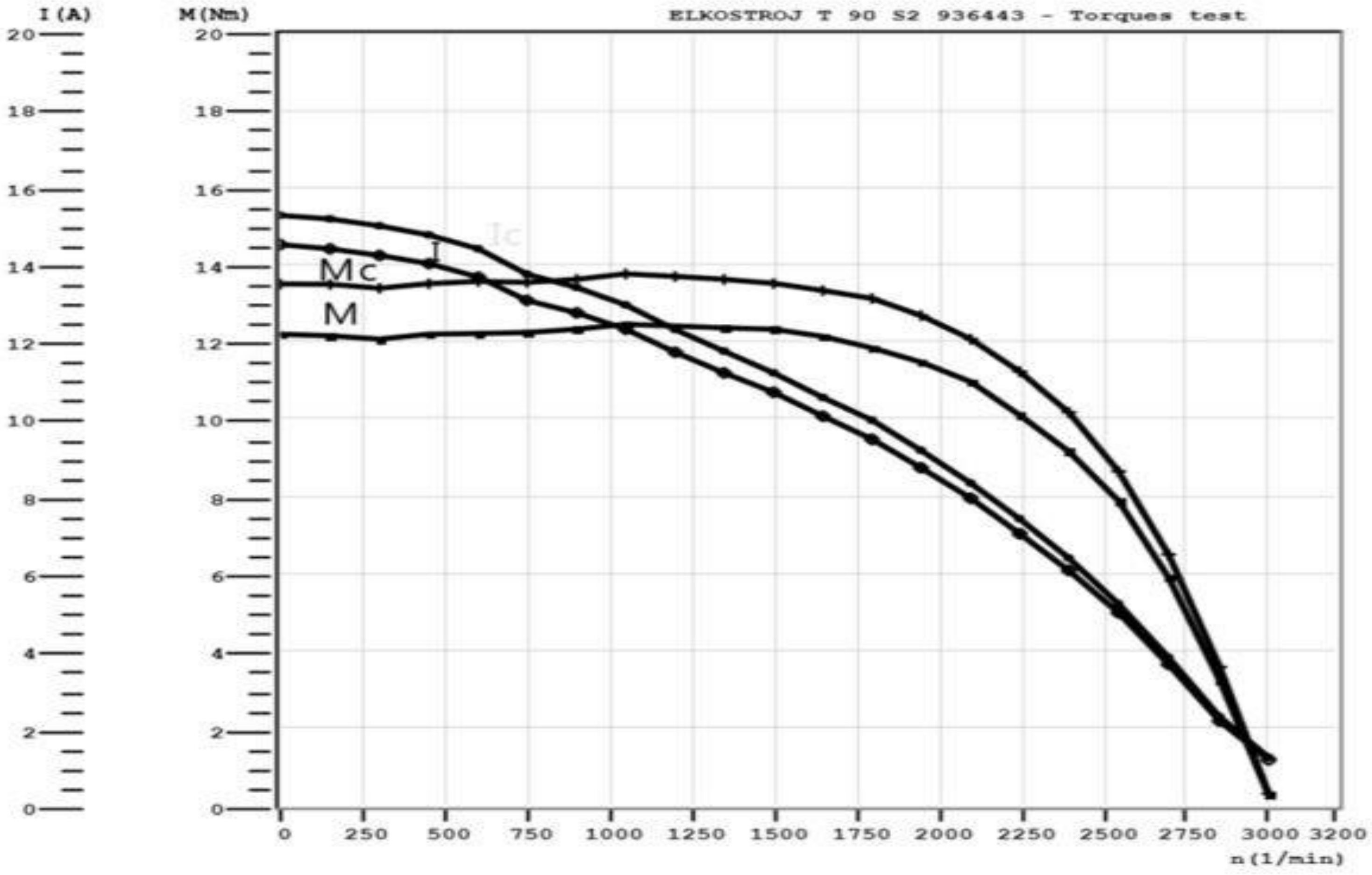
Short circuit test

U (V)	I (A)	P_{in} (W)	PF	M (Nm)
94,7	3,28	362	0,673	0,6

Measurement of resistance

Winding	resistance [Ω]
R_1	4,5
R_2	4,66
R_3	4,18
R_{13}	8,68
R_{12}	9,16
R_{23}	8,84

Motor Testing



Torque caracteristic

Thank You