Best Practice Manual in Rewinding Three Phase Induction Motors

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Acknowledgment

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In order to make sure that this manual will match the needs of the Egyptian rewinders, it was sent for review and accept the comments from both Eng. Bahaa Samy Saied, Daoud Motors Factory General Manager, and Eng. Amr El-Sayed Abd-Allah, Rotating Machines Service Manager, ABB. The author will like to thank them for their efforts and for offering their premises during the practical training sessions.

This manual of "Best Practice Manual in Rewinding Three Phase Induction Motors", was developed under the supervision of the United Nations Industrial Development Organization (UNIDO) within the scope of “Egyptian Programme for Promoting Industrial Motor Efficiency”. The project is funded by the Global Environmental Facility (GEF) and implemented by UNIDO in cooperation with the Ministry of Trade and Industry of Egypt (MTI) through the Industrial Modernization Centre (IMC).

This manual aims to help improve the capacity of motors rewinders/refurbishing workshop staff and owners (Engineers/Technicians) for better rewinding and maintaining three-phase induction motors and to disseminate the best practices for rewinding three-phase induction motors in Egypt. This manual is dedicated to engineers and technicians working in rewinding workshops aiming for high-quality performance through best practices.

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Introduction

Motors account for over 60% of industrial- and commercial-sector electricity consumption. Therefore, they are a major cause of energy costs to businesses. In Egypt, the market for low-efficiency motors has probably remained particularly dominant because electricity prices have been low due to long-lasting government subsidies which provided a weak price incentive for energy conservation.

A survey of motor users in Egyptian industry was carried out by the Energy Research Centre (ERC) of Cairo University in coordination with the Egyptian National Cleaner Production Center (ENCPC).

The survey found that:

- ✓ 77% are of very poor efficiency (much below than efficiency class IE1)
- ✓ 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 5 years.

This clearly shows that motors' rewinding is worryingly preferred by the end-users and in turn, the lifetime and the efficiency after rewinding are very low. Most of the recent studies showed that if the motor rewinding' is carried out according to the international best practices, the motors can run without any significant changes in efficiency for two rewinding cycles. Therefore, this manual "Best Practice Manual in Rewinding Three Phase Induction Motors", comes as an attempt at the "Egyptian Programme for Promoting Industrial Motor Efficiency" by UNIDO focusing on improving the efficiency of Electric Motor-Driven Systems (EMDS) and accelerating the market penetration of energy-efficient motors in the industrial sector through train motors' rewinders on the best international practices that aim at preventing motors efficiencies from deterioration.

This manual will show the best practices of motor rewinding in general, and focuses on the squirrel cage induction motors as they are the most commonly encountered type of electric motors in the industry and the other sectors. The manual was developed based on "Motor Rewinding Guideline and Repair Facility Instructions", by "Egyptian Programme for Promoting Industrial Motor Efficiency", UNIDO as well as best practices for motor repair/rewinding, presented in the Electrical Apparatus Service Association (EASA) guidelines, IEEE Std. 1068-2015, IEEE Std. 43-2015, and IEC 60034-1 to IEC 60034 -31 " Rotating electrical machines"**.** It is also based on many local and international vocational training manuals as well as many websites and YouTube videos. Which collectively contributed to the compilation, development, and preparation of this guide. They are collectively presented in the references with sincere thanks and appreciation to all authors.

Through this manual, the rewinders will be able to understand how to rewind and renew an old three-phase induction motor. They will also find how to analyze motor winding, disassemble the motor, remove bearings, copy (duplicate) rewinding, and rewinding motor, reassemble it and test the rewound motor.

Rewinding is a very long process. It needs that you practice doing it many times. Always start with simple types of rewinding and small sizes of motors. Then continue to progress step by step. Never try High Voltage Motors without long training and practices and following the necessary safety procedures and security measures.

1. What is a 3-phase Induction Motor?

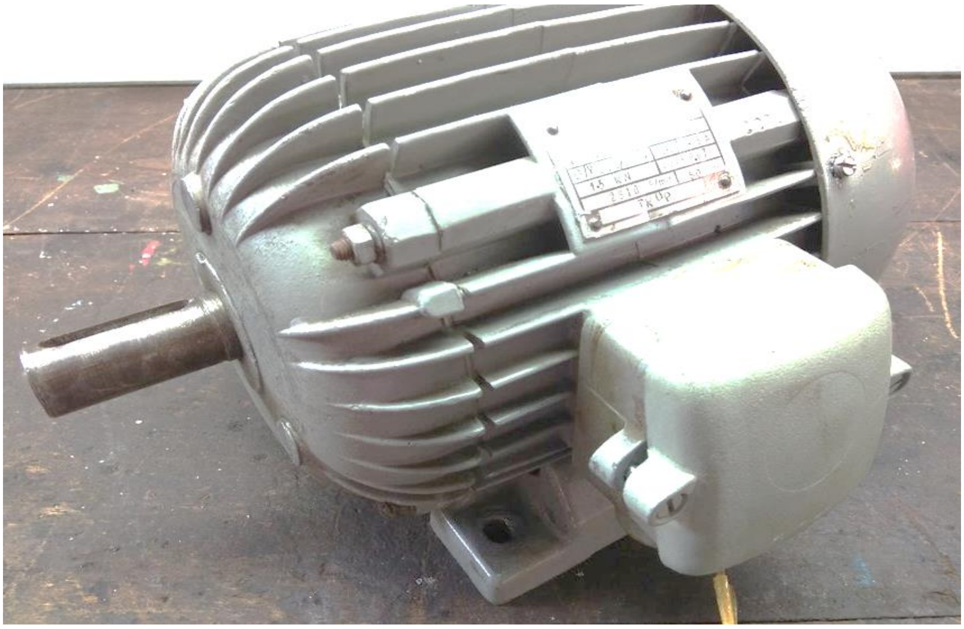


Figure 1; Three Phase Squirrel Cage Induction Motor

A three-phase induction motor with a squirrel cage is one of the most common types of electric motors in the world. This is due to the simplicity of its structure, ease of investment, few faults, cheap price, and long life. The three-phase induction motor consists of two main parts, the stator, and the rotor. The rotating part is usually manufactured as a squirrel cage and consists of a group of insulated silicon steel sheets that are fixed on the rotating shaft. It is then slit on its outer circumference and attached with rods made of copper or aluminum. The ends of the rods are connected and welded on both sides by two closed rings of the same material as the rods. It is inserted into a cavity of the stator. The stator consists of an iron core and wound coils fed from a three-phase source.

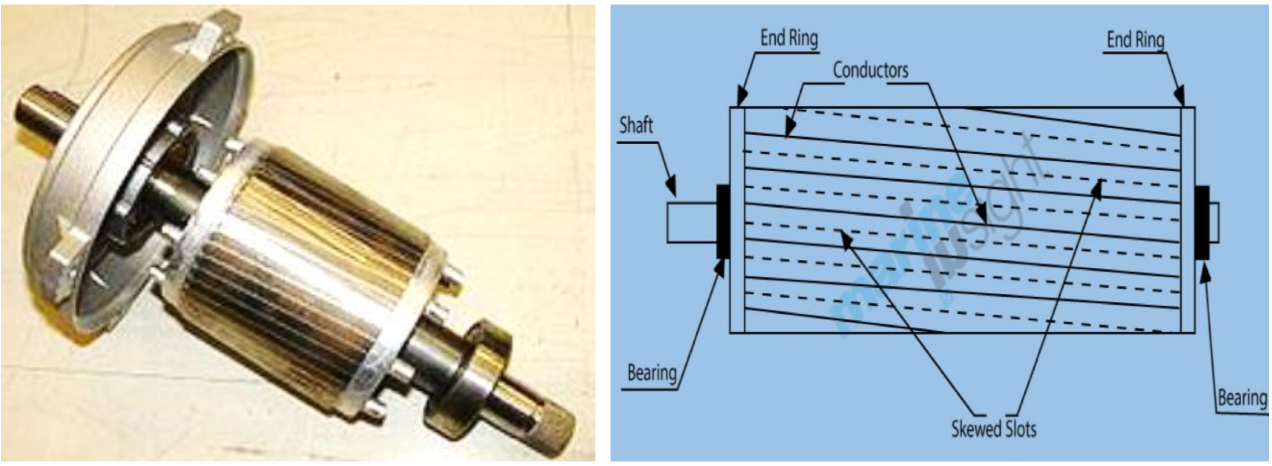


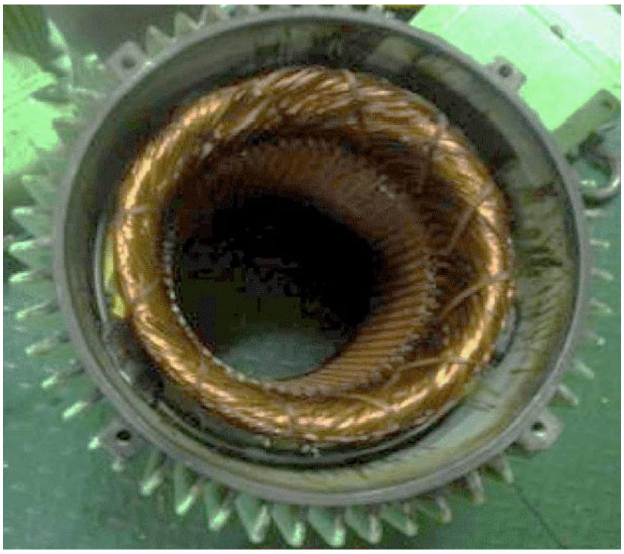
Figure 2; Rotor of 3-phase Induction Motor

The stator (the core) in the motor consists of a group of insulated metal plates to reduce hysteresis losses, as these losses are caused by magnetic fields that change according to the frequency of the source, which leads to an increase in the temperature of the metal core. This leads to the loss of part of the energy in the form of heat. The insulated metal sheets work to reduce the eddy currents caused by the change in the magnetic field in the metal core. This magneto-motive force is responsible for generating currents that flow in the form of rings on the surface of the metal core. These vortex rings are interrupted by the isolated plates and as a result, reduce heat losses in the rotor.

The stator contains three identical coils distributed uniformly and evenly in the motor's slots so that each of the phases is allocated an equal number of coils and slots. The coil of each phase must be offset from the coil of the other phase by 120 electric degrees to ensure a balanced rotation of the motor. The coil of each phase is distributed within the space allocated to it in the stator according to the so-called winding pitch, which is the distance between the two sides of one winding in the same coil. This width is determined by the distance between the slots that the coil sides occupy.

It is known that three-phase motors connect their windings, which are three-phase windings, either in the form of a star or in the form of a delta. Since these coils, which are the windings of the stator, are located so that the coil of each phase is offset from the coil of the other phase by 120 electric degrees, then balanced currents will pass in these windings between each current and the other 120 degrees, and as a result, a uniform rotating magnetic field will be created in the air gap. This magnetic field rotates at a speed called synchronous speed, as the strength of this magnetic field is directly proportional to the electrode current passing through the stator and the number of turns in the stator under each pole.

The rotating magnetic field "cuts" the squirrel cage coils (the rotor), generating an induced voltage. Because the squirrel cage rods are electrically shorted, the voltage generated creates a flow of induced current, which in turn, by being in the magnetic field, generates the force required to rotate the motor.



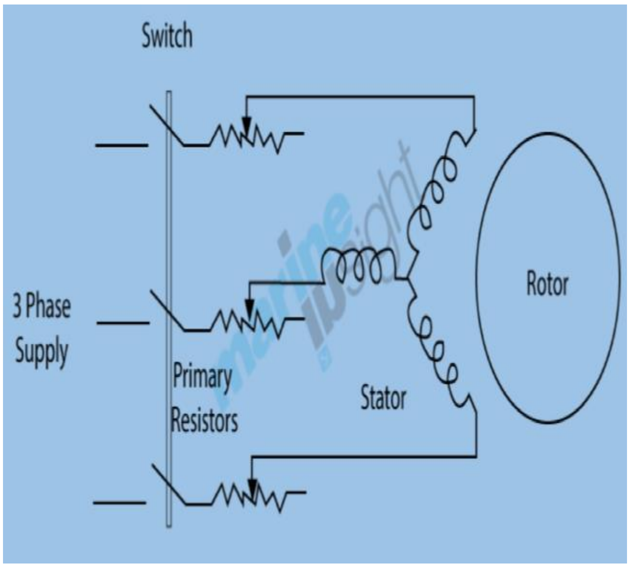


Figure 3; Stator of 3-phase Induction Motor

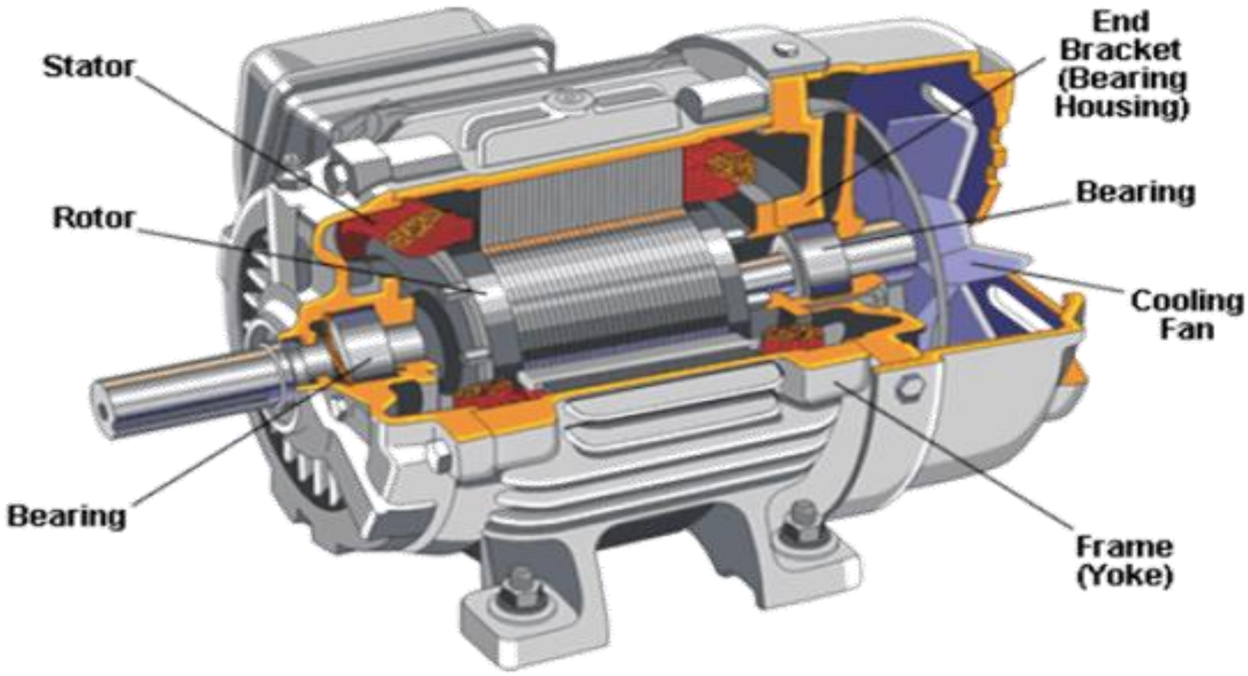


Figure 4 ; AC Motor Nomenclature

2. Wires Making Coils

Wires are made of copper or aluminum, 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. 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.

3. What Are the Properties of Conductors Making Wires?

Electrical Properties:

1. The conductivity must be good.
2. Electrical energy dissipated in the form of heat must be low.
3. Resistivity must be low.
4. Temperature resistance ratio must be low.

Mechanical Properties:

1. Good Ductility: It is that property of a material that allows it to be drawn into a wire.
2. Soldering Ability: The joint should have minimum contact resistance.
3. Resistance to corrosion: It should not get rusted when used outdoors.
4. Withstand stress and strain.
5. Easy to fabricate.

Economical Factors:

1. Low cost
2. Easily available
3. Easy to manufacture

Characteristics of a Good Conductor Material: The conductor materials should have low resistivity so that any amount of power can be transmitted without much loss in the conductor. Commonly Used Conductor Materials: Copper and Aluminum. In Egypt Copper is usually used even if the original windings are made of Aluminum.

4. What Are The Different Types and Use of Insulating Materials?

Insulation Tapes: Insulation tapes are used to cover the windings (coils) on the overhang side. Shellac or varnish are applied over this covering to prevent it from absorbing moisture and improve insulation strength. 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, Glass Fiber tape, Empire cloth tape, 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 specifically designed for insulating electrical circuits. 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 the types.

Insulating varnishes:

Varnish coating, also called Secondary Insulation, 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.

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

Impregnating varnish: After the motor has been wound, welded, bonded, and tested, the next process is varnishing. This process resists moisture and also prevents the wiring coils from vibrating in the slots.

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. The filling of empty spaces not only gives mechanical strength but also hinders or 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 370^{o}C depending on the inter laminations' varnish withstand temperature.

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 120^{o}c to 450^{o}c for a duration of 3min. to 60 min, depending on the grade of the varnish.

Properties of Insulating varnish coating after curing: Varnish after application and after undergoing the required curing process at appropriate temperature forms into a uniform film on the materials. The elastic varnish film has very good mechanical properties such as hardness, flexibility, penetration, good adhesion, and Bonding strength. The cured film is resistant to moisture, dilute acids, alkalis, chemicals like benzene & Toluene, oils, and tropical climate from 0^{o}C to 55^{o}C. It has good dielectric behavior and dielectric strength.

Applying Varnishes: For treating coils, windings, and insulating parts with insulating varnishes the methods generally used are Vacuum Impregnation and hot dipping. Finishing varnishes are usually applied by brush or spray. Mica sticking varnishes are applied by brush or sometimes using a roller after being dipped in the varnish. Synthetic varnishes are frequently used for impregnation by dipping and require baking to develop their properties fully.

5. What Are the Principal Areas Where Insulation Must Be Applied?

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

6. What Are The Electrical Insulation Classes?

Classification according to temperature: The insulating materials are classified mainly based on the thermal limit. The performance of the insulation depends on its operating temperature. The higher the temperature, the higher will be the rate of its chemical degrading, and hence the lower will be its useful life. If a reasonably long life of insulation is expected, its operating temperature must be maintained low. Therefore, it is necessary to determine the limits of temperature for the insulation, which will ensure safe operation over its expected life.

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 fiber, 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).

7. What Are The Types of Slot Insulation?

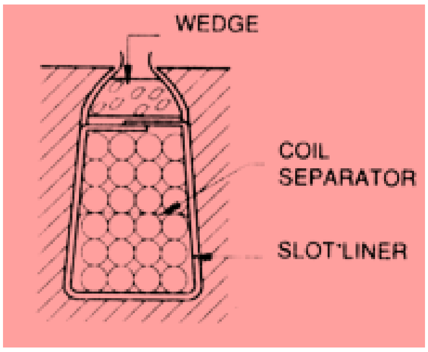


Figure 5; Slot Insulation

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

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

Insulation Tape: It is inserted between the coils after they are dropped into the slots. Sometimes it is also used as a slot liner.

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.

8. Why Your Motor May Need Rewinding?

Figure 6; Rewinding the Motor

If you've been told that an electric motor needs rewinding, that means the coils are shorted, grounded, or otherwise damaged. 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.

In this manual, you will be able to understand how to rewind and renew an old three-phase induction motor. You will also find how to analyze motors' winding, disassemble the motor, remove bearings, calculate new winding, rewinding motor, and reassemble it as well as test the rewound motor. Rewinding is a very long process. It needs that you practice doing it many times. Always start with simple types and then continue to progress step by step. Never try High Voltage Motors without long training and practice.

9. Windings' Configurations

A length of wire lying in the magnetic field and in which an emf is induced is called a coil. The coils used in windings are shown in the below figure.

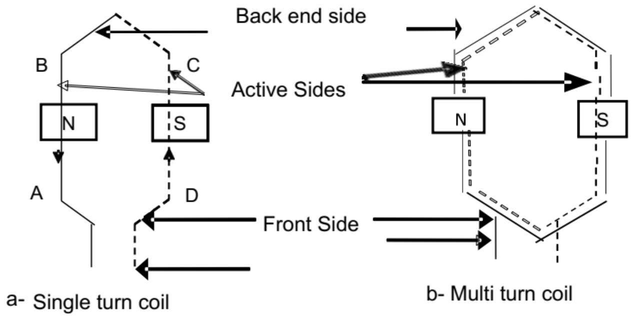


Figure 7; Winding Coil Representation

Figure 7 (a) represents a coil with only one turn in it. Each coil has active and inactive sides. A coil can in general has any number of turns. A single turn/coil has two active sides, otherwise called conductors. Similarly, a two-turn coil has four conductors and a three-turn coil has 6 conductors. Generally, the total number of conductors per coil,

$Z_C = 2T$

And, the total number of conductors for a given machine

$Z = Z_C.C$

Where: Z_C = total number of conductors per coil

C = number of coils

Z = total number of conductors

T = number of turns per coil

Figure 7- (b) represents a multi-turn coil.

The active side of a coil: It is the part of a coil that lies in the slots under a magnetic pole and an emf is induced in this part only. In Figure 7- (a) above, coil sides AB and CD are called active sides. For a double layer winding, one-half portion of the coil drawn with a solid line corresponds to the coil side-lying on the top of a slot, and the dotted line corresponds to the coil side lying in the bottom layer of another slot. This type of representation is used for double layer winding. For a single layer winding, the complete coil is represented by a solid line.

Inactive side of a coil: The inactive side of a coil consists of two portions, namely the front-end side and the back-end side. In Figure (a) above, the portion of the conductor which joins the two active sides and is placed around the core is called the back-end side of the coil. The portions which are used to connect other coils are called the front-end side. These ends have two leads called starting end S and finishing end F of a coil. In Figure 7- (a), AD and BC represent the inactive sides of a coil.

Coil Groups: One or more coils connected in series are called coil groups, as shown in Figure 8 below. The number of coil groups is equal to the number of poles. In the figure, there are four coil groups, which are equal to four numbers of poles. For AC winding, the total number of coil groups depends upon the number of poles and the number of phases.

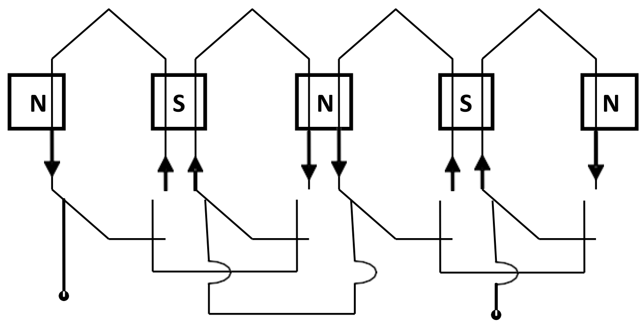


Figure 8; Coil Groups

The total number of Coil groups = mP

Also, total number of coil groups/phase= $\frac{\text{Number of coil groups}}{\text{Number of phases}}$

= mP/m

where m = number of phases

P = number of poles.

Example: Find the total number of coil groups for a 3 phase 6 pole machine.

Solution:, coil groups = mP = 3 x 6 = 18.

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 = $\frac{\text{Number of slots}}{\text{Number of Poles}}$ =S/P = 180^{o}_{ed}

where S = number of slots

ed = electrical degree

Example: Calculate the pole pitch for a three-phase 4 pole ac machine having 36 stator slots.

Solution: Pole Pitch =S/P = 36/4 = 9

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.

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

Example: Find the angle between adjacent slots of a 3 phase, 6 pole motor having 36 slots.

Solution: Slots per pole = 36/6 = 6 Then, â = 180 / (SP) = $30\ ^{0}_{ed}$

Pitch factor or coil span factor or chording factor, K_P:

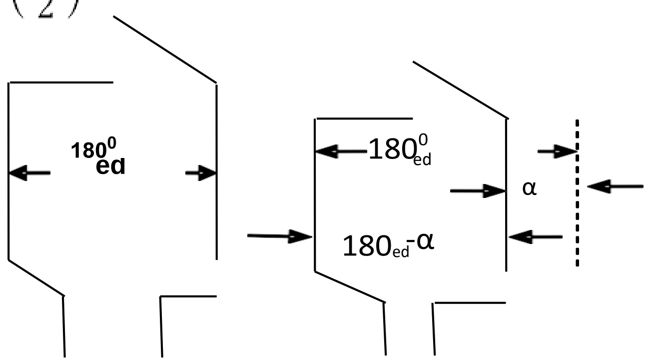
When the two sides of the same coil are short-pitched by an angle á, the emf induced in the two coil sides have a phase angle difference of $\underline{\alpha}\,^{0}$. Due to phase angle difference, the actual emf is reduced by a factor $\underline{\cos \alpha/2}$ and is called pitch factor, coil span factor, or chording factor.

$K_p = \cos \alpha/2$

Example: Find the pitch factor for a 3 phase 4 pole ac machine wound in 36 slots with a coil span of 140^0ed.

Solution: Short pitch angle, $\alpha = 180^0 - 140^0 = 40^0{}_{ed}$.,

$$K_P = \cos\left(\frac{\alpha}{2}\right) = \cos\left(\frac{40}{2}\right) \quad 0.94$$



(a) (b)

Figure 9, Full Pitch and Short Pitch Coils

Distribution Factor, K_d: 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.

$$K_d = \frac{\sin\left(\frac{m\beta}{2}\right)}{m \sin\left(\frac{\beta}{2}\right)}$$

Where $$\beta = \frac{180}{S/P}$$

$m = \frac{S}{3p}$ = number of slots per pole per phase

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: $m = \frac{36}{3x4} = 3$

The angle between adjacent slots:

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

Then: K_d= 0.96

10. Torque, Flux, and Winding Rules

The following rules are important when changing a winding configuration. In an induction motor, torque is proportional to flux times current. Both can be affected by changes to the winding, and thus both can be affected by rewinding. The voltage applied to each phase of the motor is opposed by (and almost equal to) the back emf (induced voltage in a coil caused by the conductors moving through or cutting field magnetic lines of flux). The back emf is expressed by the formula:

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

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

For a rewind (other than for a different voltage or frequency) E and f are constants. That leaves three variables the control of the repairer:

N – The number of series turns/phase
Kd– The winding distribution factor under
Kp – The chord factor (pitch factor)

The product of these variables must remain constant to satisfy the above equation, and this gives rise to the following important rules for a given winding configuration:

- ✓ Increasing the turns, the chord factor, or the distribution factor reduces the flux.
- ✓ Reducing the turns, the chord factor, or the distribution factor increases the flux.
- ✓ The flux/pole will remain unchanged if the product of the chord factor, the distribution factor, and the turns remains unchanged.

To maintain motor performance, both torque, and efficiency, the flux/pole should remain unchanged. The effectiveness of a winding in terms of optimizing motor performance (including efficiency) depends both on the type of winding used and its design, which needs to optimize Kp and Kd such that fundamental emf's per coil is maximized and harmonic emf's minimized.

11. 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.

Figure 10; Single Layer and Double Layer Winding

12. Mathematical Rules for Winding Motors

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

   = ... coils

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

   = ... slots/poles.

3. Pole pitch $= \dfrac{\text{No. of slots}}{\text{No.of Poles}}$ = = ... 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 .... = ...

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

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

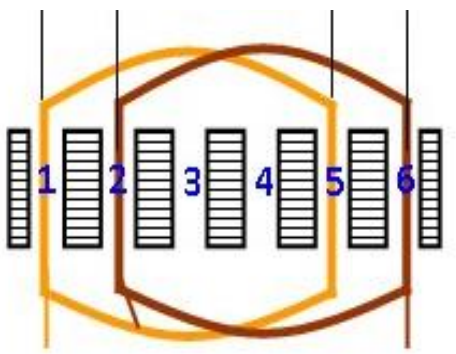
10. Winding sequence

If 1st phase starts in the ....
2nd phase starts in the ....
3rd phase starts in the ....

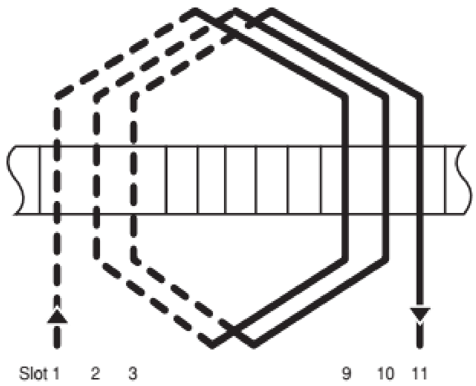
Figure 11; Mathematical Rules for Motors' Winding

13. Coil Winding

Lap Winding: As shown in Figure 12, 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.



Lap winding
Equal coil Pitch

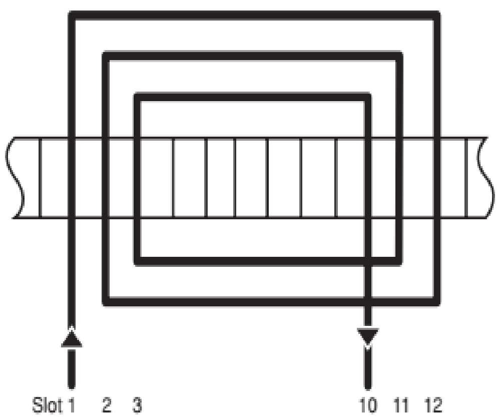


Coil group for double-layer lap winding
Winding short-pitched 1-9 (span 8)
Dotted lines indicate coil sides in the lower half of slots

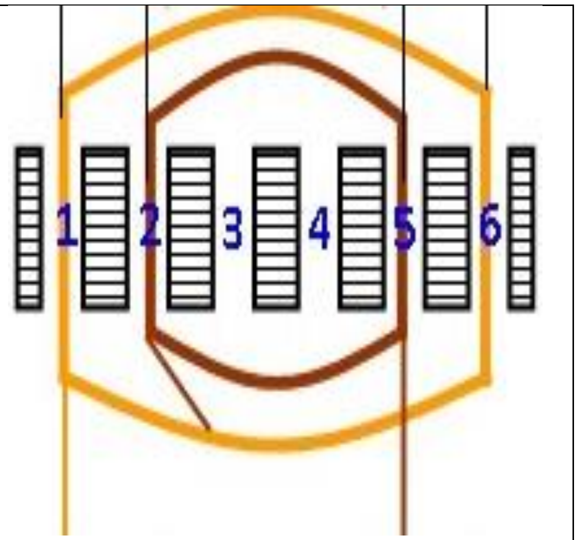
Figure 12; Lap Winding

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. These windings are so designed that the effective coil span of the winding is equal to that of a winding as a full pitch winding with some of the coils having a span greater than a pole pitch, some with less than a pole pitch but an effective span which makes the winding behave as if it had full pitched coils. This is shown in Figure 13.

Unequal Coil Pitch



Concentric Winding
Unequal Coil Pitch



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

Figure 13; Concentric Winding

14. Connecting Coil Groups

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.

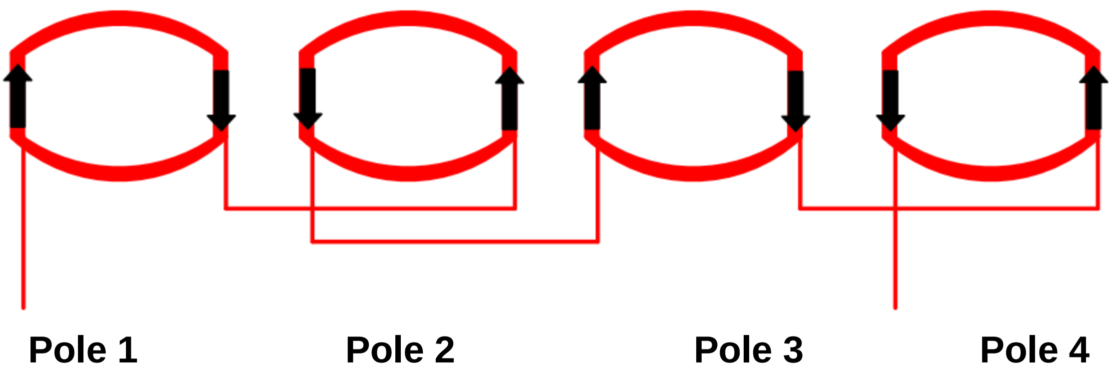


Figure 14; Whole Coil Winding

The number of poles is equal to the number of coils in the group = 4

Figure 14 shows a group of four coils of one phase connected to form many poles equals four poles.

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.

Figure 15 shows a group of coils connected as two groups of one phase to form some poles equal to four poles.

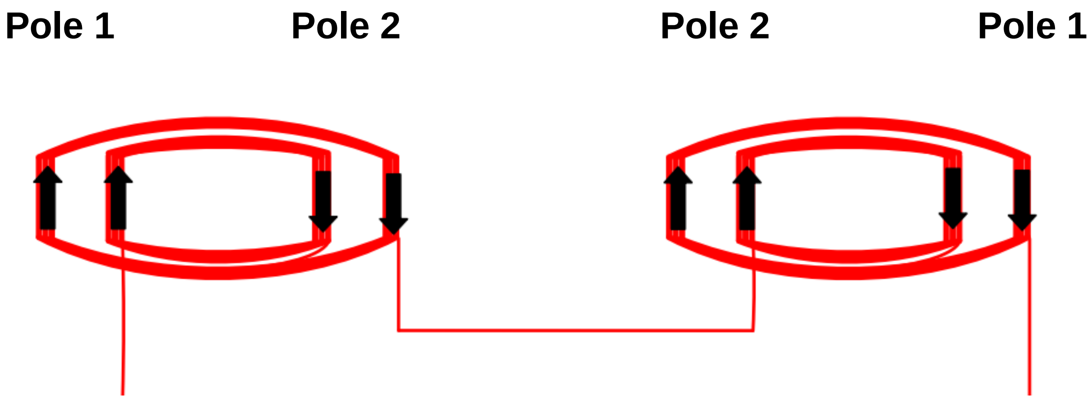


Figure 15; Half Coil Winding

The number of poles (4) is equal to double the number of groups (2)

15. Winding Sequence Examples

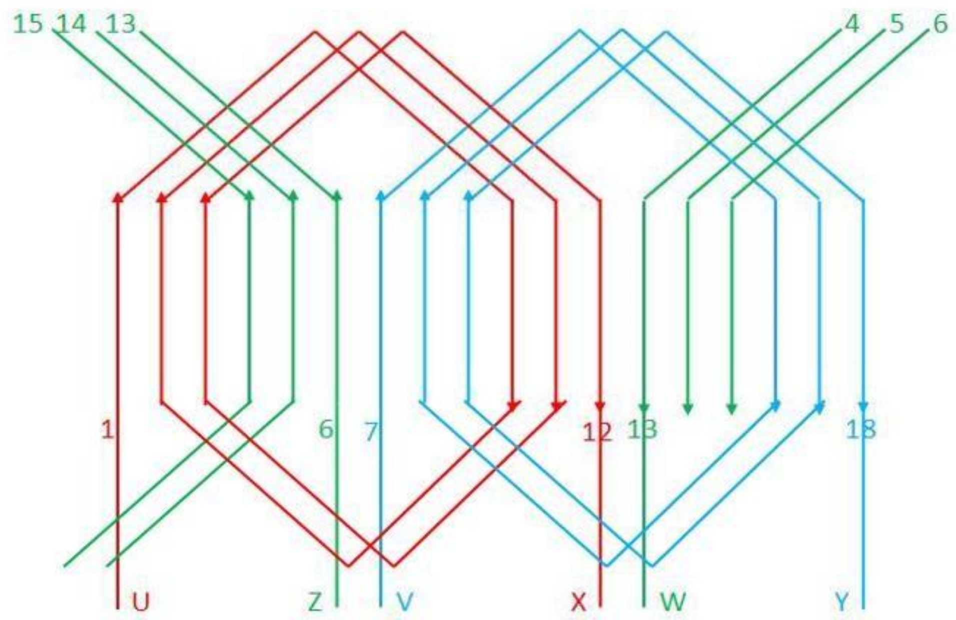


Figure 16; Figure 16; 3 Phase – 2 Pols - 18 slots - Single layer – 50 Hz

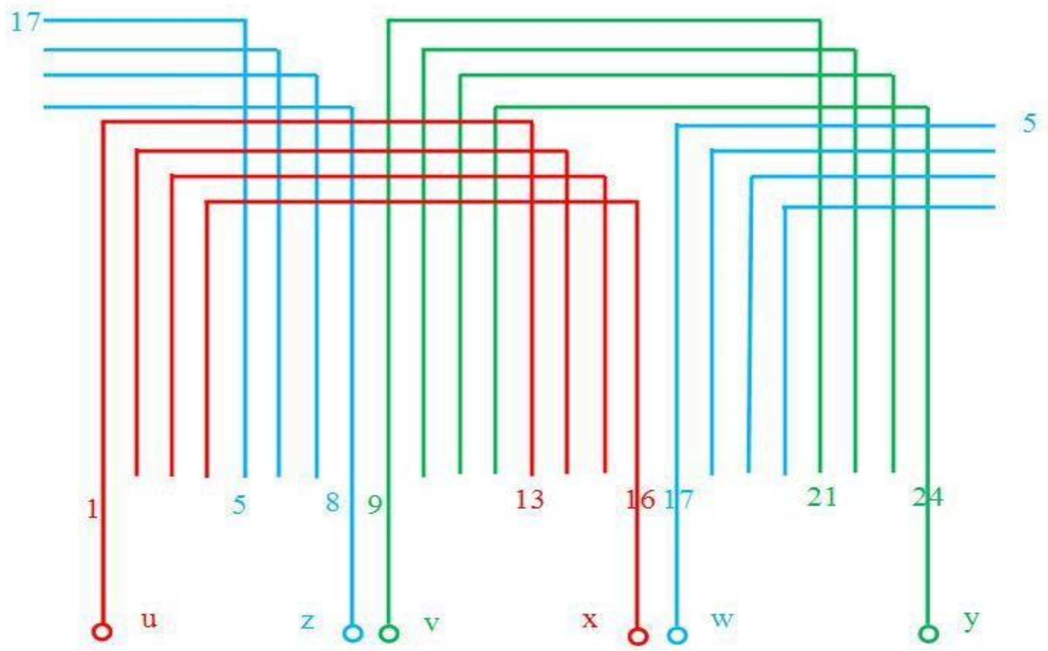


Figure 17; 3 Phase – 2 Pols - 24 slots - single layer – 50 Hz

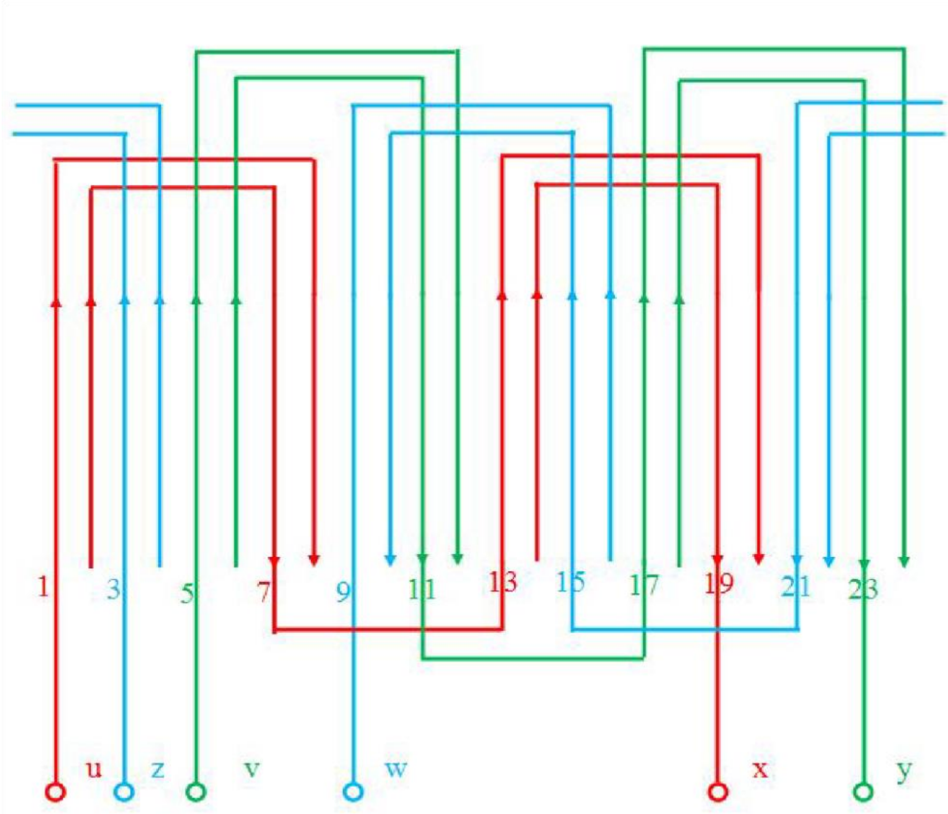
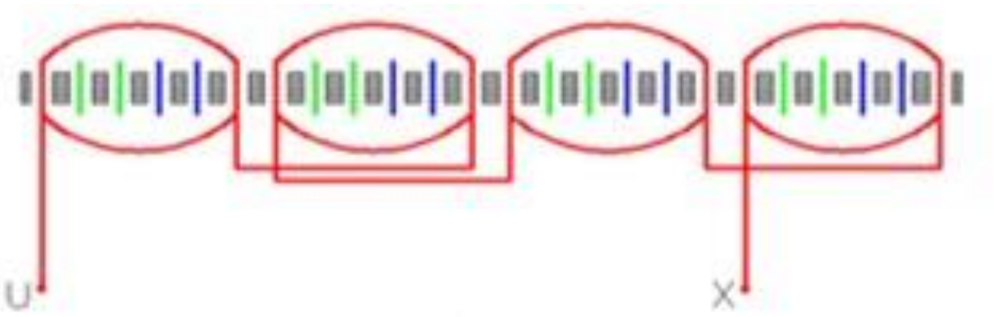
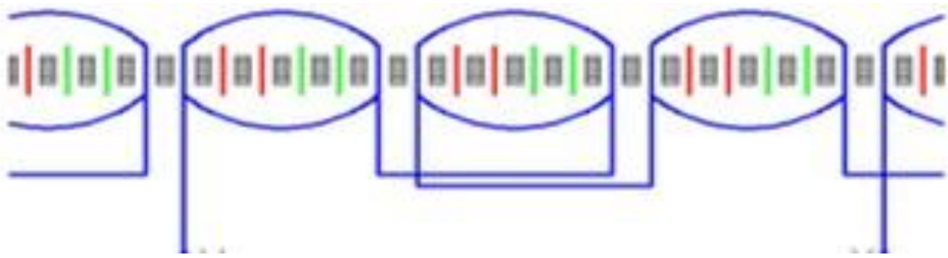


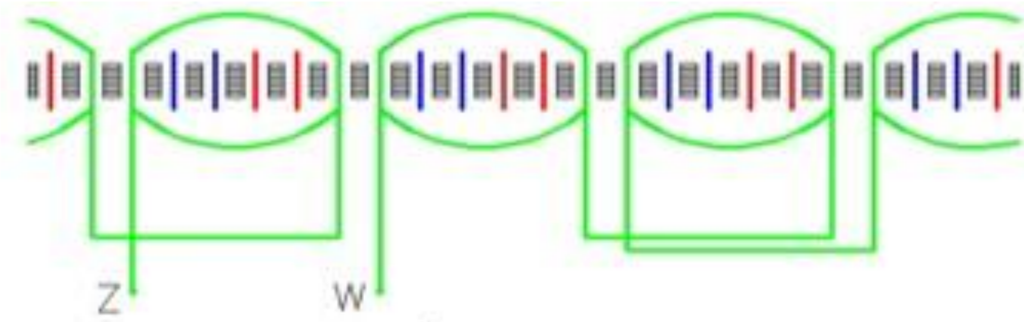
Figure 18; 3 Phase – 4 Pols - 24 Slots - Single Layer Concentric Winding – 50 Hz



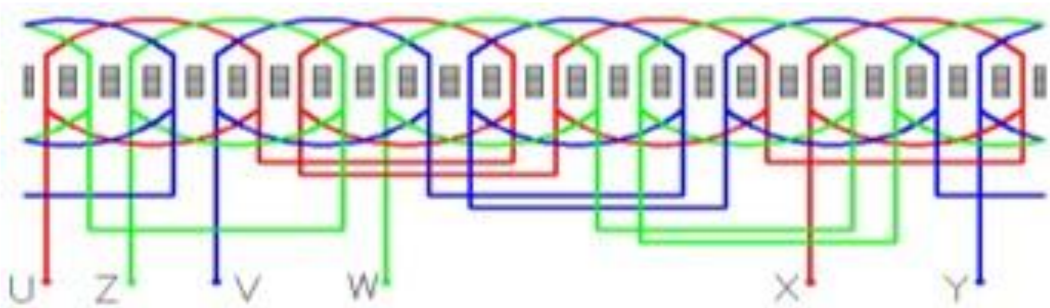
Phase 1



Phase 2



Phase 3



The 3 phases

Figure 19; 3 Phase – 4 Pols - 24 Slots - Single Layer Lap, Winding – 50 Hz

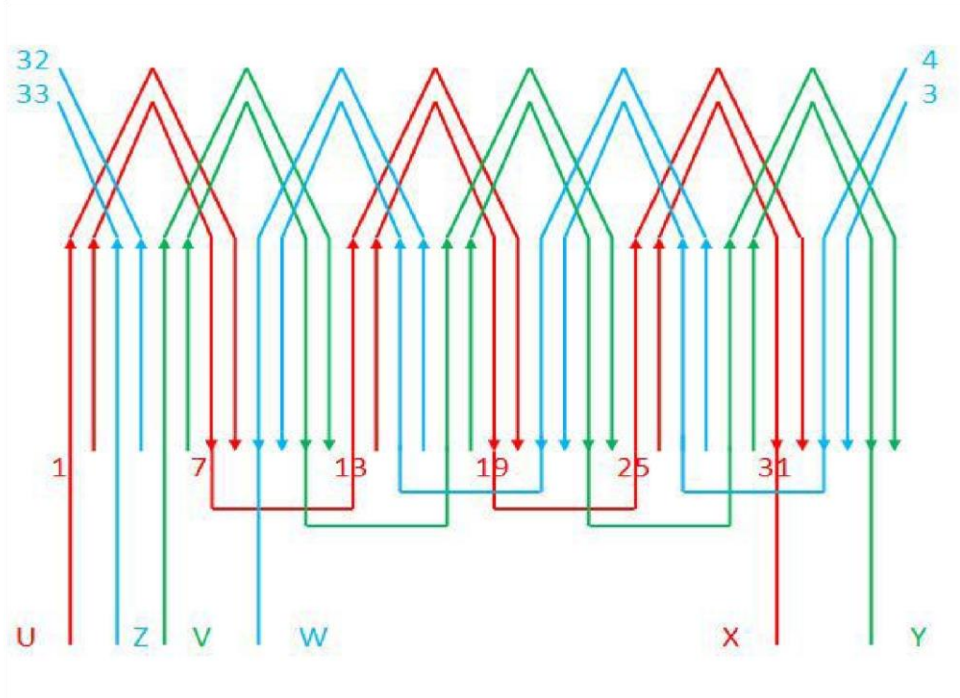


Figure 20; 3 Phase – 6 Pols - 36 Slots - Single Layer Concentric Winding – 50 Hz

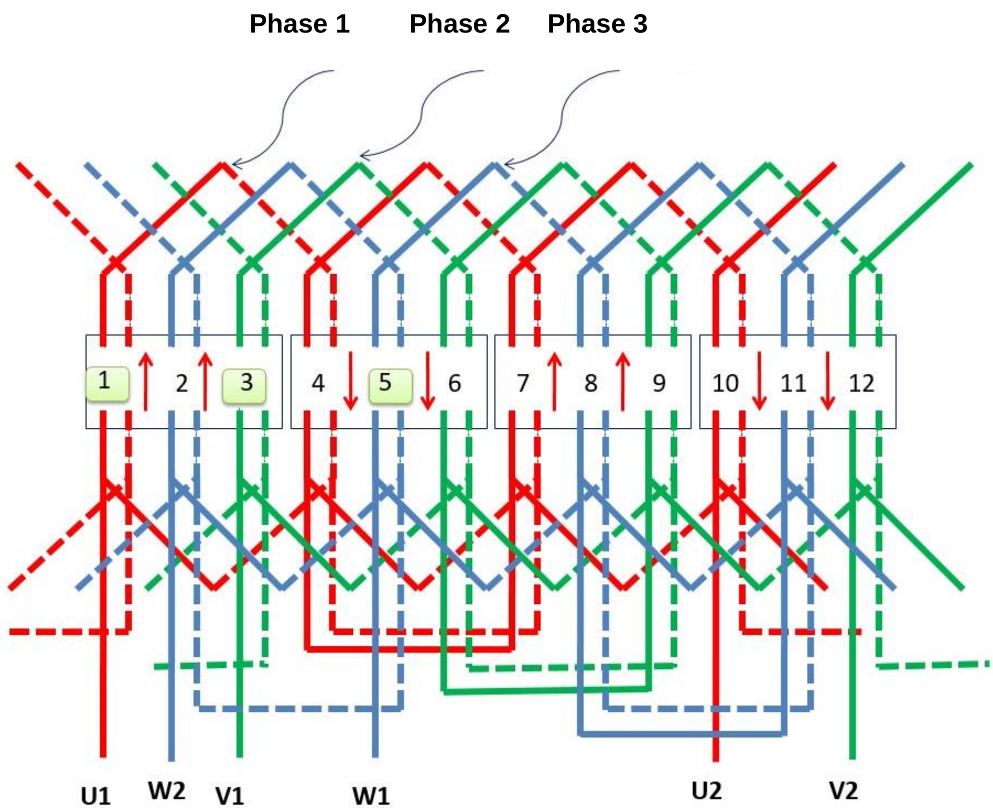


Figure 21; 3 Phase – 4 Pols - 24 Slots - Double Layer – 50 Hz

16. Steps of Rewinding an Electric Motor

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.

17. The Main Influences of Rewinding Coils

Is the old winding the manufacturer's original?

Experienced technicians often can tell by looking at a winding that it was wound by the manufacturer. Even so, it usually is best to check the winding data on EASA's Motor Rewind Data CD-ROM. This resource, which is available to EASA and AEMT members, contains over 340,000 sets of data. If the repairer has a winding data bank, this may provide useful information as well.

There are other clues, however. For example, repairers rarely use concentric coil groups. Then, too, repairers often are more careful about layering wires neatly in coils than are manufacturers. They also tend to use larger lead wire sizes and more substantial phase insulation and bracing. These differences are not a criticism of manufacturers' windings. They merely reflect the fact that manufacturers' winding processes are often wholly or partially automated, whereas almost all repair work is done by hand. Most service centers also try to prevent future failures of the motors they rewind by upgrading the coil bracing, insulation systems, etc.

Copy (duplicate) rewinding:

If the details of the old winding have been recorded and provided that it is the manufacturer's original winding, the core can now be prepared for rewinding. Even though the coil pitch (or pitches), turns/coil, and the connections will be the same as those of the original winding, two changes could be made that will help to maintain or even slightly improve the efficiency of the rewound motor:

A- Minimize the length of the coil extensions.
B- Increase the copper cross-sectional area in each coil.

A. **Minimizing the length of the coil extensions**

The coil extensions consist of "inactive" copper that merely connects the "active" conductors or coil-sides inside the slots. For most stator windings (especially in 2-pole and 4-pole motors) the copper in the coil extensions weighs more than the copper in the slots and contributes substantially to the total stator I2R losses. It is therefore important to keep the coil extensions as short as possible. If the mean length of turn (MLT) of the rewind exceeds that of the original, the I2R losses will increase. Attention to the following rules will prevent this:

- ✓ Keep the coil extensions within the measured dimensions of the original winding.
- ✓ 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.

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. Cooling may even be affected, in extreme cases causing the motor to run hotter.

By careful specification of the winding and coil dimensions, it is nearly always possible to equal or improve the performance of the manufacturer's original winding concerning copper losses. Record coil dimensions of the new winding.

B. Increase the copper cross-sectional area in each coil

It often is possible to increase the copper cross-sectional area in each coil when hand-winding motors that were originally machine wound, or when rewinding an older motor. The drawbacks are that it takes more copper and can add significantly to winding times if overdone. It also is harder (and may even be impractical) to do with energy-efficient motors.

Where practical, though, increasing the copper cross-sectional area of each coil helps reduce I^2R losses and maintain (or improve) motor efficiency after a repair. Experience will tell how much the copper area can be increased. The best method is to change conductor sizes in each coil, remembering that the slot fill (i.e., the cross-section of copper in each slot/slot area) increases if fewer, larger conductors are used, but so does the difficulty of inserting the winding. Be sure to record the conductor sizes used in new winding.

Key points in copying rewinding

- ✓ 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).

C. Changing to a Two-Layer Lap Winding (not recommended for rewinding workshops)

Repairers often prefer to use lap windings because all coils are the same. This is acceptable if the new winding has the same flux/pole as the original. Single-layer lap windings are sometimes used for small to medium-sized motors because the coils are easier to insert and no separators are required. This allows more room for copper.

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. Lap windings should be appropriately short-pitched (i.e., the coil pitch must be less than the pole pitch unless the winding has only one coil per group).

Advantages

- ✓ Efficiency can be maintained or improved. The double-layer winding yields the best results.
- ✓ Mean length of turn (MLT) can be made the same as, or less than, that of the original winding.
- ✓ All coils are the same.
- ✓ All coils have equal exposure to airflow for cooling.
- ✓ The magnetomotive force (MMF) curve more closely resembles a sine wave.
- ✓ Phase insulation and coil bracing are more likely to be uniformly placed.

Disadvantages

- ✓ None provided that the conversion is done correctly.

18. What are Energy Losses in AC Motors?

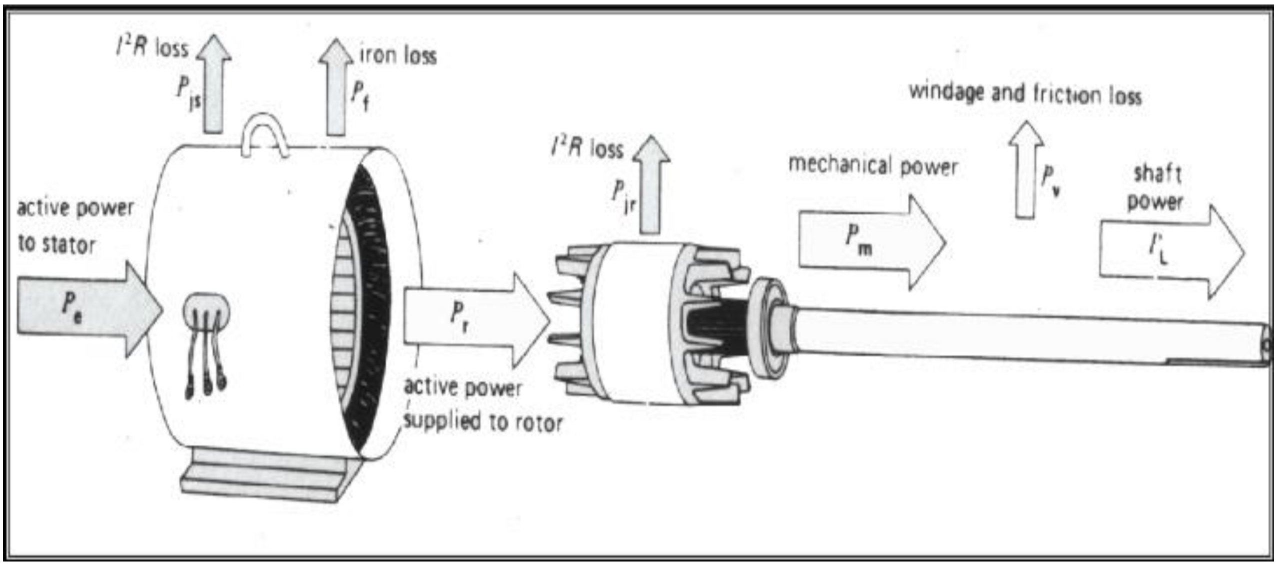


Figure 22; Schematic Diagram Showing Losses in Three-phase Induction Motors

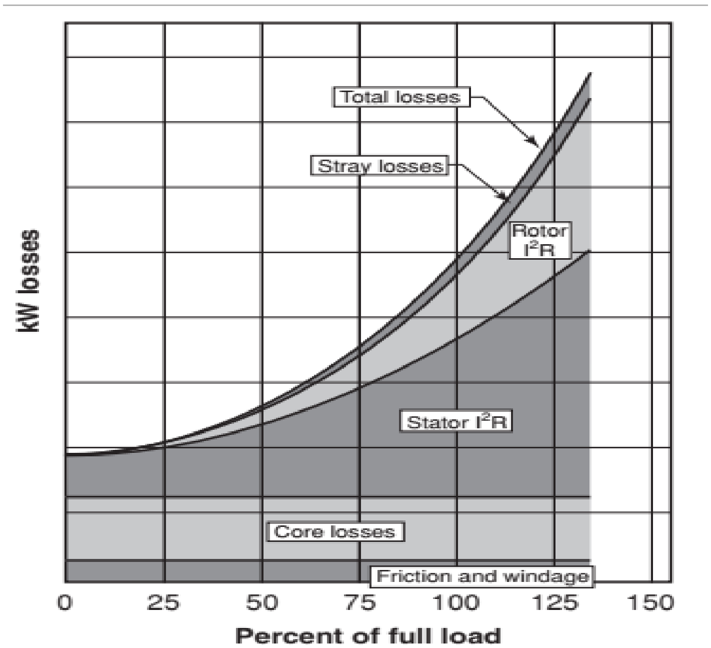


Figure 23; Different Losses Components as a Function of Motors' Loading

19. Factors Affecting the Different Energy Loss Components in Induction Motors

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)

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

Rotor losses:

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

Friction and windage losses due to changes of:

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

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

20. Motor Repair Processes

Most repair processes, if done improperly, can reduce motor efficiency. Conversely, doing them well will maintain and may even improve efficiency. It is also important to keep clear, concise written records throughout the repair process.

The main motor repair processes include:

1- Checking if the motor needs rewinding,
2- Gathering motors data,
3- Dismantling the motor,
4- Documenting and removing the old winding and cleaning the core,
5- Rewinding the motor,
6- Mechanical repairs,
7- Reassembling the motor.

20.1. Checking If The Motor Needs Rewinding

If you've been told that an electric motor needs rewinding, that means the coils are shorted, grounded, or otherwise damaged. 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.

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.

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.
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

4-

Figure 24; Injection Voltage and Acceptable Resistance

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 in Figure 24. You can also detect burned motors winding by its unique smell (smells like burned lacquer).

20.2. Gathering Motors Data

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. Some codes, numbers, or letters which seem meaningless may be very important. 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…

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:

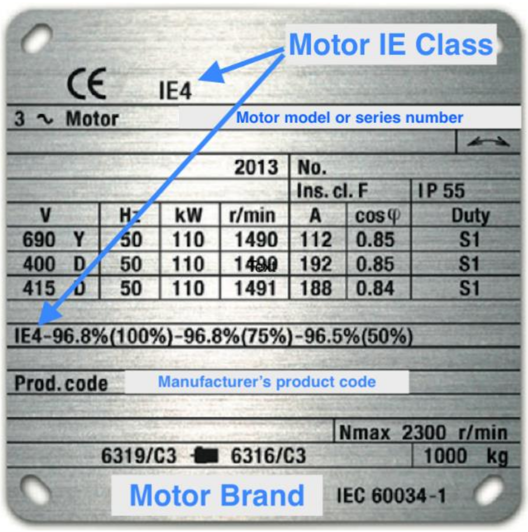


Figure 25; Motors Rating Plate (Nameplate)

- ✓ 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-)
- ✓ 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

Step 3: Customer Input

Customers may be able to provide:

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

20.3. 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 center punch before dismantling the motor. Document the mounting position of the shaft to the leads. You could even make a video recording of the deconstruction process to ensure that you're recreating the original winding pattern and connections precisely. Place all parts that are not to be repaired in a suitable bin or tray that is labeled with the motor serial number or job card number.

Required Records:

Required Records:

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

Step 1: Removing Covers

Figure 26; 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 the cover and stator, you can use a rubber hammer. Gently hit the cover and try to rotate.

Step 2: Removing the Fan

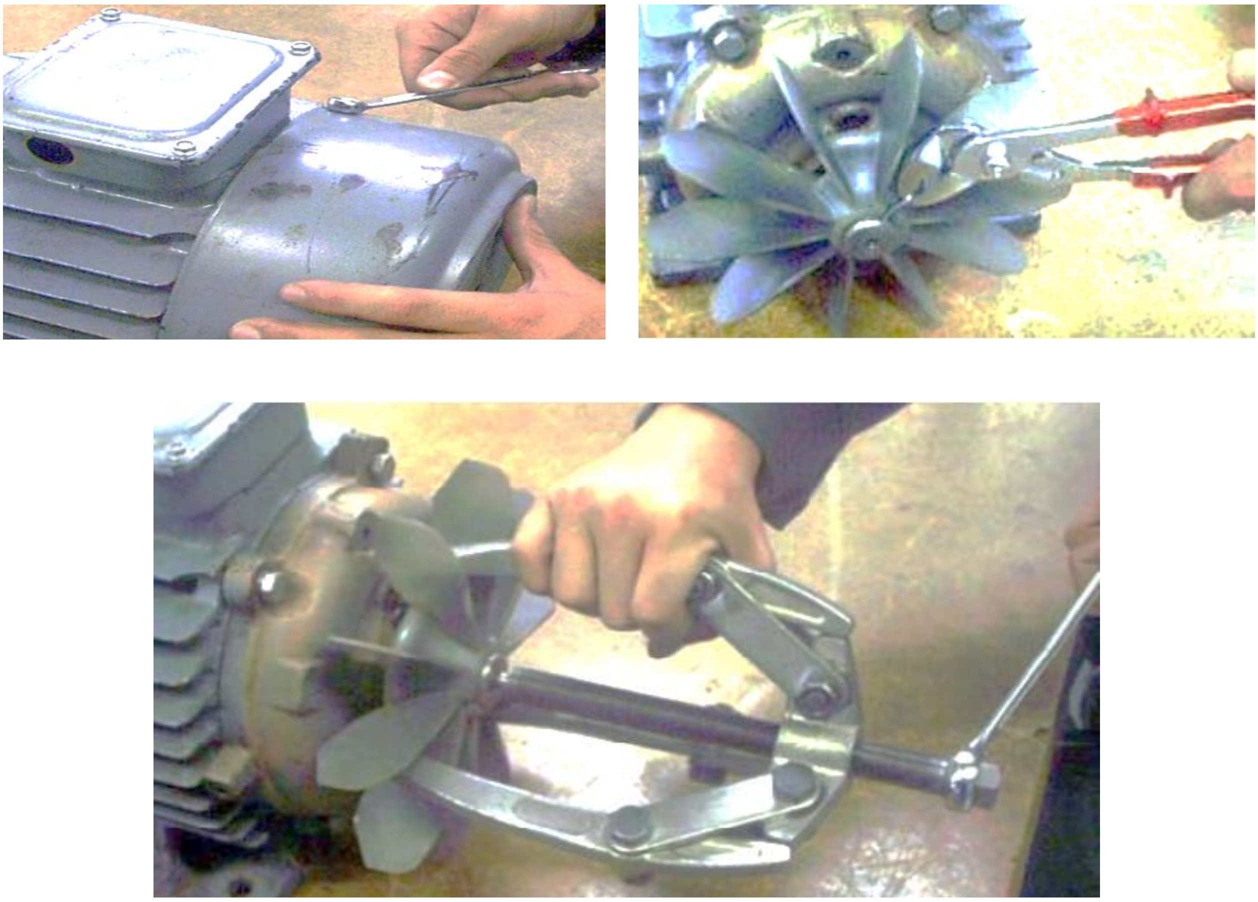


Figure 27; Removing the Fan and the Second Cover

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

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 the rotor.

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.

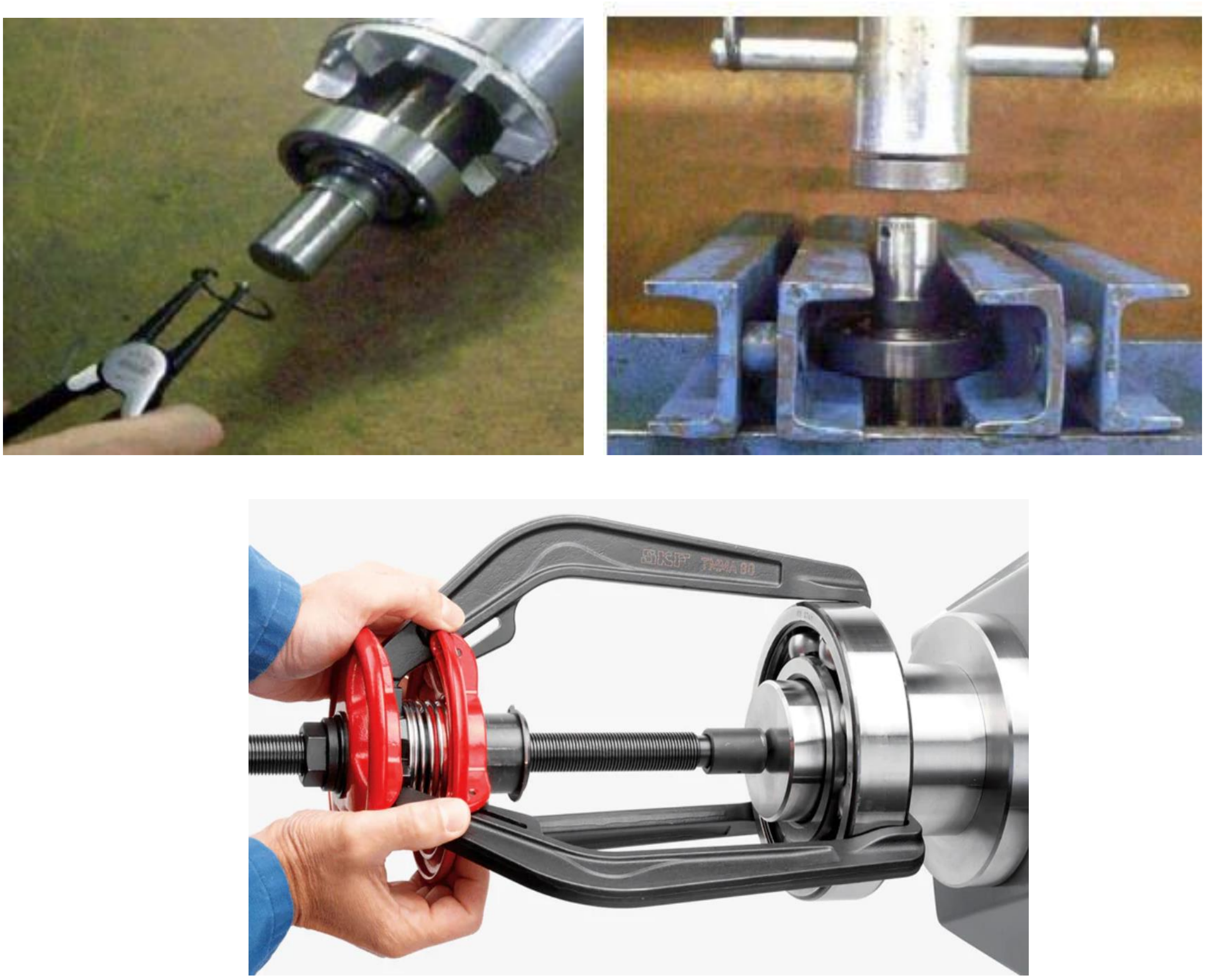


Figure 28; Removing the Bearings

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 considerable 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.

For small motors, you can gently hit the rotor's 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 of large motors.

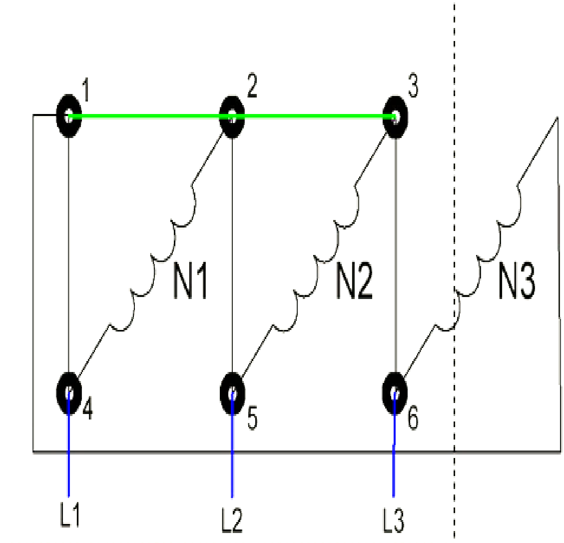
Figure 29; Remove Rotor from Stator

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.

Step 5: Terminal Box Layout and Connections

- ✓ Open the cover of the terminal box.
- ✓ 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.



a. Star Connection **b. Delta Connection**

Figure 30; Terminal Box Layout and Connections

Before measuring remove all connections in the terminal box. Repeat the measurements carried out in Step.2 – 20.1 above 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 in Figure 24. You can also detect burned motors winding by its unique smell (smells like burned varnish).

20.4. Documenting and Removing the Old Winding and Cleaning the Core

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 indicated in Annex 1.

Commercial core loss testers can indicate whether or not the stator core losses have been increased by the rewind process. They normally will not record the same core loss as would be measured during a load test on the same motor. One reason for this is that the distribution of the flux induced by the tester in the core is not the same as that induced by the machine's winding, particularly when the rotor is removed. Inaccuracies tend to worsen approaching the operating limits of the tester, so always use testers well within the manufacturer's recommended operating range.

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. It 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 the quality of how the rewinding process was conducted. Also, make sure the tests are conducted well within the manufacturer's recommended operating range for the tester being used.

Remember that figures obtained are comparative, not actual losses. If the core loss increases by more than 20% (the typical acceptable range of losses is ≤ 8 watts/kg for core weight).

- ✓ Make sure the settings of the core loss tester have not been changed and repeat the test.
- ✓ If the repeated test confirms the increased loss, repair the core or consider replacing it.

Figure 31; Core Test

Step 2: 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.

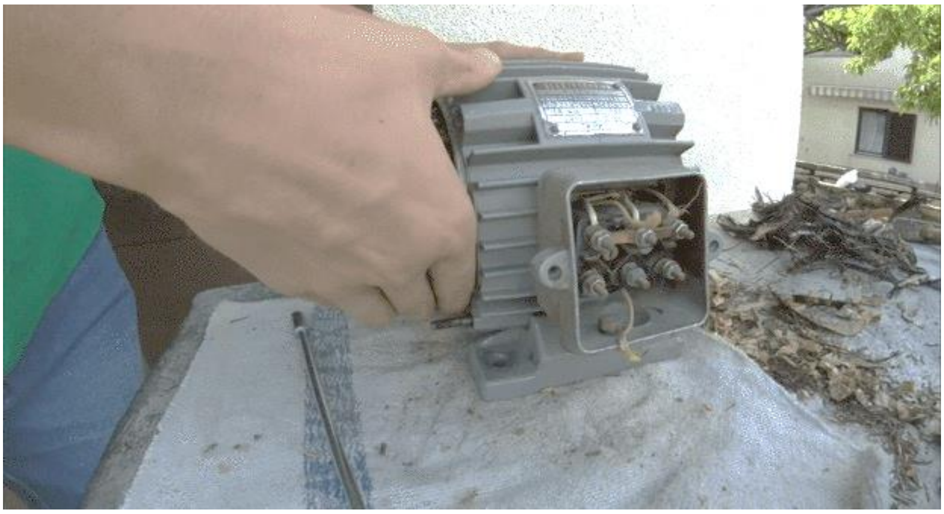


Figure 32; Empty Terminal Box

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.

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 250ºC and 350ºC 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 370ºC if the inter-lamination varnish type permits.

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. You need to make sure the oven is recording oven temperature and part temperature to ensure the motor doesn't get too hot and damage the core insulation. The oven should also have a water suppression system to help keep the heat from getting too high. This burn-out step can take up to multiple days for larger motors and results in the insulation essentially being reduced to ash.

Figure 33; Controlled Temperature Burn-out Oven

Step 3: Cut Off and Stripping Out Windings

In this step, the existing motor windings are stripped out of the motor core. 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. Positioned the stator for the type of cut-off equipment you will be using. A number of cut-off tools and machines are available commercially for this purpose. 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. You may also use a cut-off machine or cut-off and extraction machine as seen in Figure 35. For large motors, you need a 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.

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 an extraction machine, you may use a puller or use a pair of wire cutters as in the first coil extension. Be sure to count the number of turns in each coil so that you can rebuild the motor in the exact same configuration.

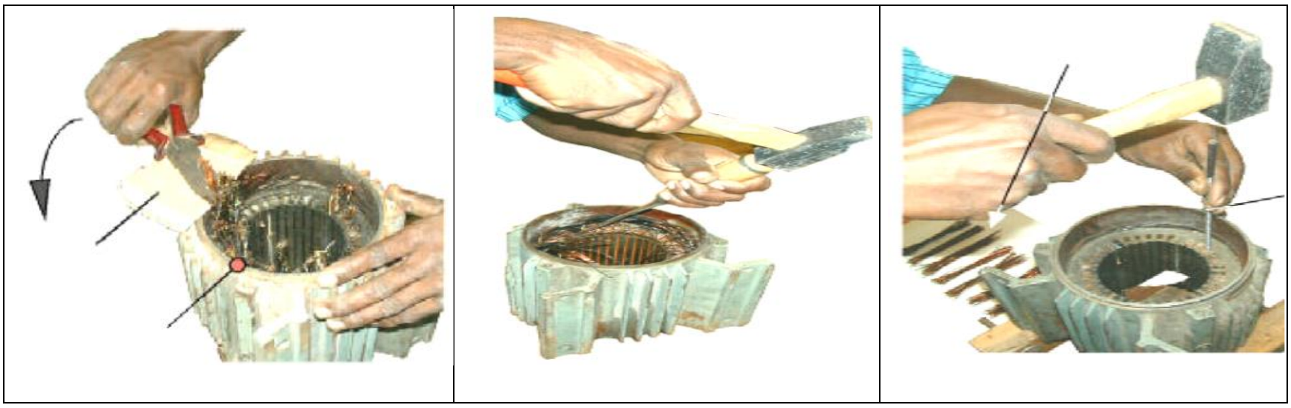


Figure 34; Winding Cut-off Manually

Winding Cut-off machine

Hydraulic coil cut-off and extraction machine

Figure 35; Winding Cut-off Machines

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.

You can find all information about the type of old winding in "winding head". The winding head is part of the 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

.

Figure 36; Burned Winding Head

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 of slots
- ✓ Number of poles
- ✓ Number of phases
- ✓ Number, size, and marking of leads
- ✓ Turns/coil
- ✓ Number and size of wires in each coil with and without varnish
- ✓ Grouping
- ✓ Coil pitch
- ✓ Connections
- ✓ Weight of a single coil and weight of total winding
- ✓ Front and rear end bearing numbers and types

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		

Figure 37; Example of a Data Collection Sheet

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.

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 is 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.

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.

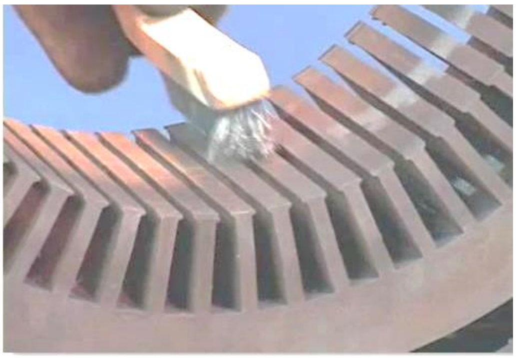


Figure 38; Cleaning the Stator Core

Perform sandblasting which is the process where fine sand hits the surface of the workpiece with very high speed and slightly removes 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.

Figure 39; Sandblasting and Painting the Stator

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).

20.5. Mechanical Check and Repair (Not Part of the Rewinding Steps)

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.

20.6. Rewinding the Motor

Step 1: Isolating Stators Slots

First, pull the old paper out of the slots in the stator using a pair of pliers or tweezers and make sure the empty slots are free of debris. Measure the length of the slot, and add about 12 – 16 mm (depending on how you will twist insolating paper). Put the isolating paper on a table. Cut it and twist it as shown in the below steps in Figure 40, 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.

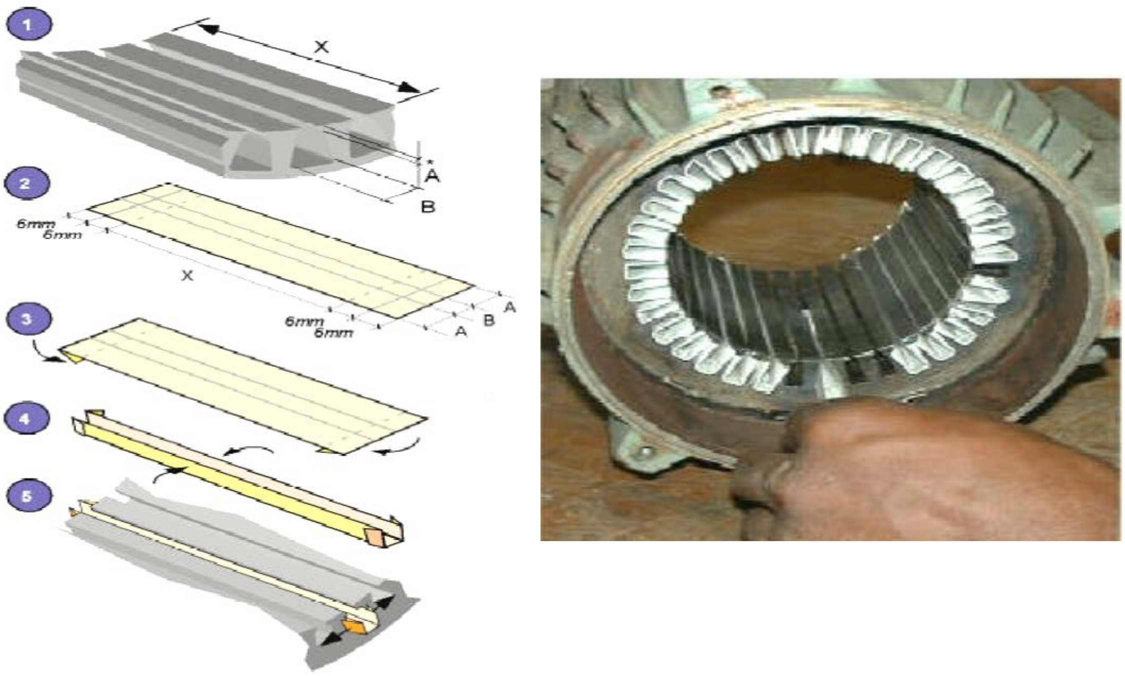


Figure 40, Isolating Stators Slots

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.

Figure 41, Completely Isolated Stators Slots

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. 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.

Manual **Semi-Automatic** **Automatic**

Figure 42; Coil Winding Machines

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.

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.

Use a winding tool. Make sure you wind the correct number of turns. After you wind the 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.

Step 3: Inserting Coils in Stators Slots

If the details of the old winding are recorded, the iron core can be prepared for rewinding. Before we start the process of dropping the coils, it must be taken into account 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. 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.

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 a 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.

Inserting coils **Marking coils' ends**

Figure 43; Inserting Coils in Slots

Figure 44; Tamping Tools

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.
- ✓ 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).

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.

Figure 45; Connecting Coils

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.

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.

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 Annex1**.**

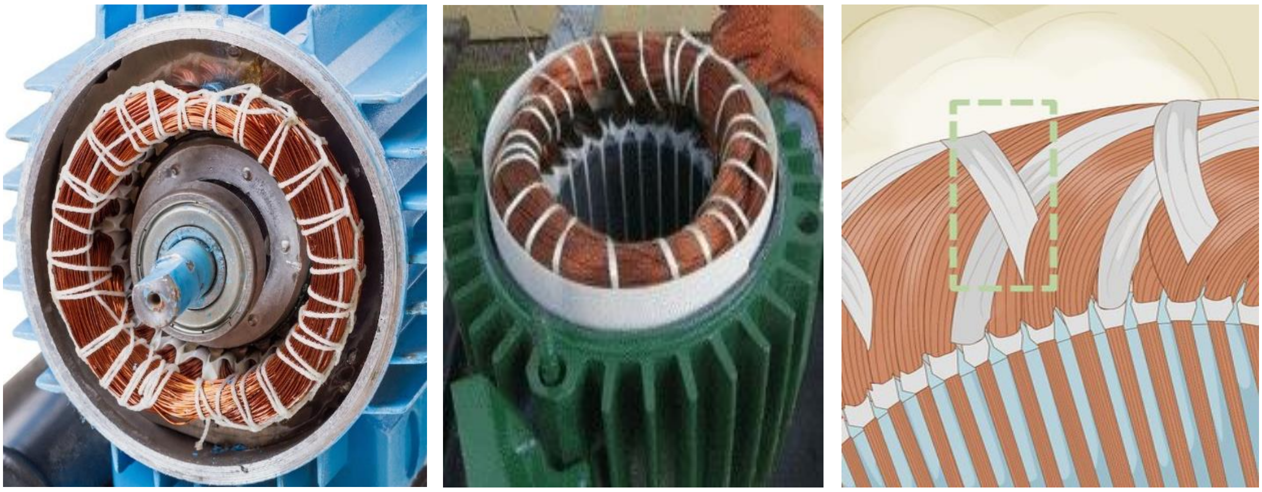


Figure 46; Lacing and Bracing Windings

Step 6: Varnishing the Motor - Vacuum Pressure Impregnation

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.

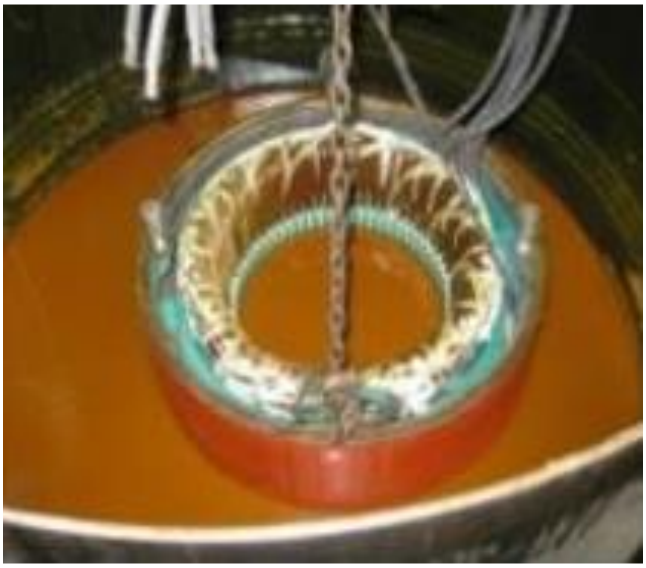


Figure 47, Varnish Dip

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.

1. 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).

Figure 48; Vacuum Pressure Impregnation

20.7. Reassembling the Motor

Step 1: Reattach Bearings

To re-attach the bearings, lubricate of rotor axis then use a hydraulic press or a steel tube of the same diameter as the bearings and a hummer. If you need to change the bearings, replace them 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 the matching model number in the catalogue on the internet.

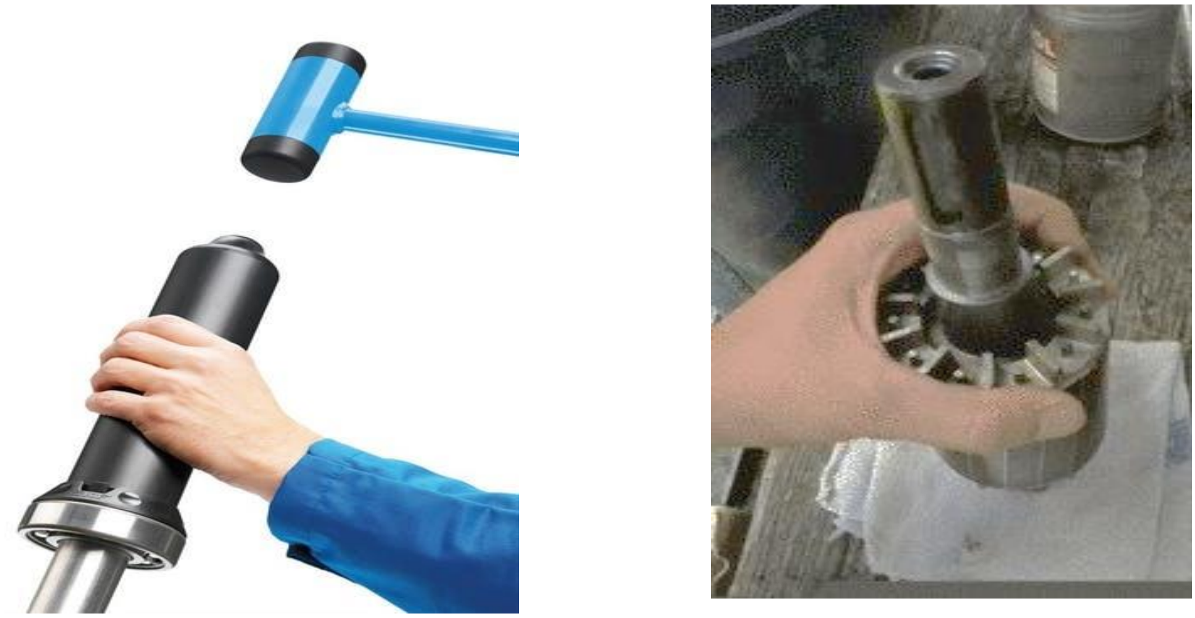


Figure 49; Re-attach Bearings

Step 2: Attach Cover

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

Figure 50; Attach Cover

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.

Figure 51; Putting the Rotor into Stator

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

Connect the end of the coils to clips, according to the data collected in Figure 30.

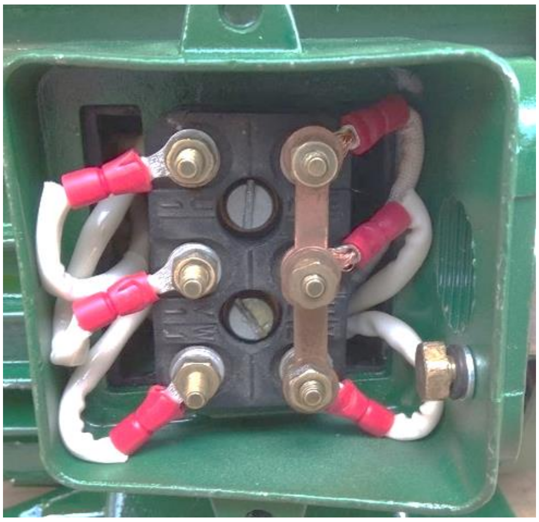


Figure 52; Connect End of Coils to Clips in the Terminal Box

Step 5: Reassemble Fan and Fan Cover

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

Figure 53; Reassemble Fan and Fan Cover

21. Motor Testing

To perform full tests to determine the motor efficiency and the other characteristics according to the international standards, mount the 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:

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1. Resistance of winding
2. Free running test of an electric motor
3. Test of the loaded electric motor
4. Optimal voltage test
5. Short circuit test
6. Torque characteristics

Figure 54; Testing the Motor

Measurement of resistance

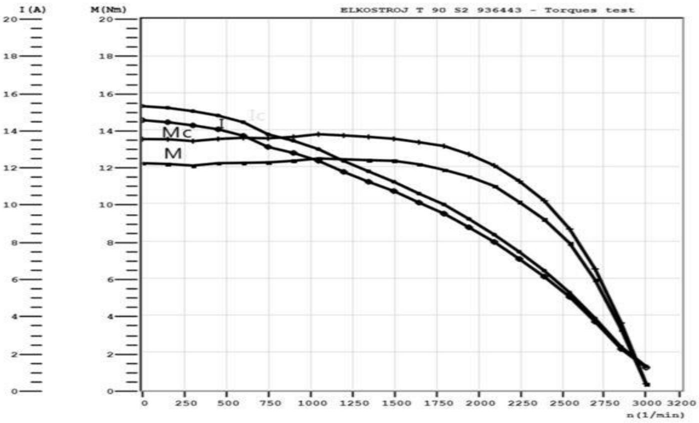
Winding	resistance [Ω]
R_1	4,5
R_2	4,66
R_3	4,18
R_{13}	8,68
R_{12}	9,16
R_{23}	8,84

Short circuit test

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

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



Torque caracteristic

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

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

Figure 55; Examples of Test Results

Annex 1: What Is Meant By Motors' Testing?

A1.1. Continuity Test

Continuity refers to being part of a complete or connected circuit. In motors, when an electrical circuit is capable of conducting current, it demonstrates electrical continuity. It is also said to be “closed,” because the circuit is complete. In the case of a light switch, for example, the circuit is closed and capable of conducting electricity when the switch is flipped to “on.” The user can break the electrical continuity by flipping the switch to “off,” opening the circuit and rendering it incapable of conducting electricity. In short, by performing a continuity test, we can determine the following

i) existence of continuity in the electrical wiring circuit
ii) existence of any open circuit in the circuit
iii) existence of any short circuit in the circuit

Several devices are manufactured to assist rewinders in testing electrical continuity, ranging from multi-meters (AVO) which have a wide range of additional applications, to simple electrical continuity testers that light up if electrical continuity is present. These devices use two electrical probes, which form a complete circuit when touched together. Consumers can test the device to ensure that it is working properly by turning it on and touching the probes together – the meter should read zero, or the indicator light should turn on, indicating a closed circuit. When the probes are not touching anything, the metered device will read infinity, showing that the circuit is open.

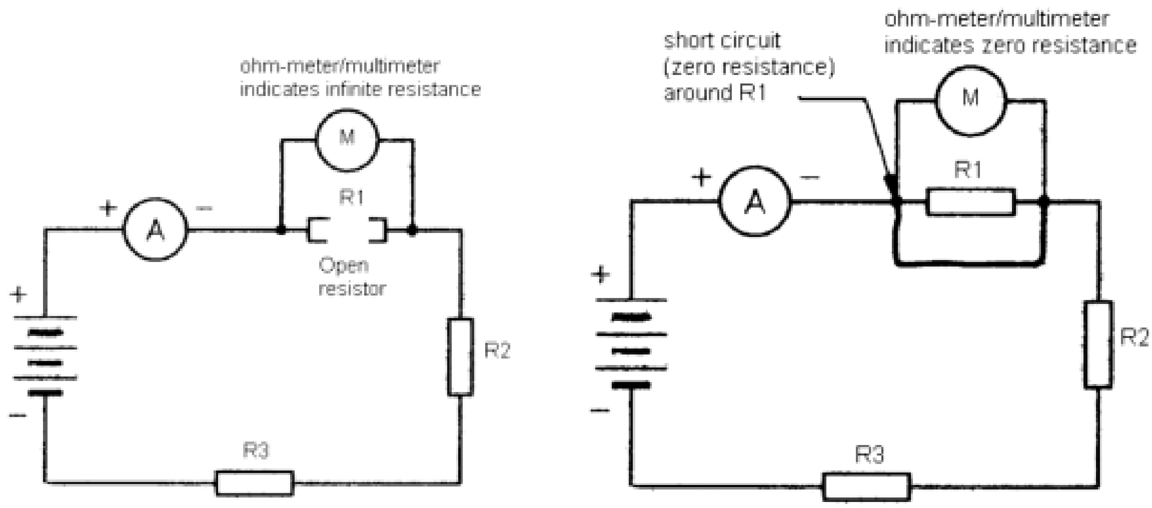
Analog Multimeter

Digital Multimeter

Figure 56; Analog and Digital Multi-meter

Open circuit test and short circuit test:

An AVO meter may be used for this test. For this, the AVO-meter must be placed in the resistance measurement mode to check the presence of any open circuit or short circuit between any two points in the electrical circuit wires. Any electrical source in the circuit must be disconnected first. Then 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 "0" ohms it indicates a short circuit.



Open Circuit Test **Short Circuit Test**

Figure 57; Using AVO to Identify Open Circuit and Short Circuit

Motor Testing:

1- Measure winding resistance test and continuity test for each phase coil individually 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 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.
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.

A1.2. Insulation Testing

This testing is important, as 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. Leaking current also results in higher electric bills. In addition, 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 Tester (Megger):

The Megger applies DC voltage to the insulation system and measures the current that results. The results of the test show if the insulation is working well, or if it is allowing current to leak.

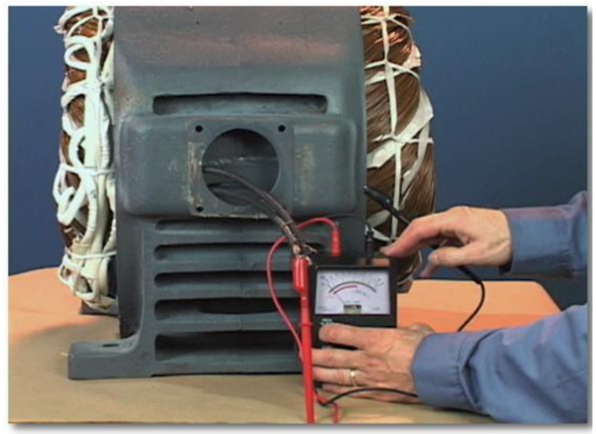


Figure 58; Megger

Megger, the insulation tester, is a combination of a hand-driven generator and a true ohmmeter at the same time. The generator produces 1000 V dc and supplies it to the mega- ohm meter section.

Precaution while using insulation tester (Megger):

I. Portable testers (meggers) come in 50, 100, 250, 500 or 1000 volts. It is important to use the right tester for the right system. Low voltage testers are required for low voltage systems and high voltage testers for high voltage. Higher voltage is generally used for commercial systems, motors, or transformers. Some digital testers work over a range of voltages and can be set for higher or lower volts.

II. Before applying the tester, be sure to disconnect the power from the system being tested.

III. Disconnect all electronics. These can get damaged during the testing process. Double-check to be sure all electronics are disconnected before testing. This is a common and very costly mistake.

During the test between each phase and the motor frame, the resistances shall be per the following IEC 60034-2 t, and IEEE Std. 43-2015, Figure 59. 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

Figure 59; Injection Voltage and Acceptable Resistance

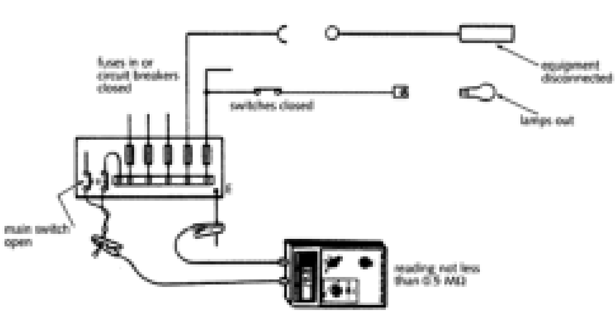
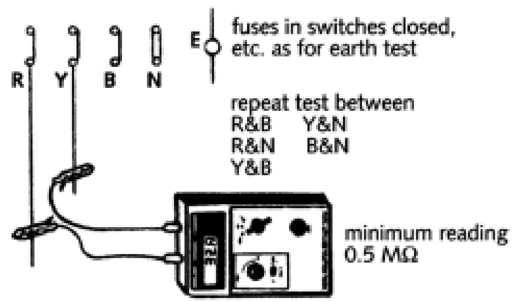
Insulation Test to Earth	**Insulation Tests Between Phases**
	

Figure 60; Samples of Insulation Testing

A1.3. Winding Tests

Test the winding using the winding resistance tests and phase balance tests.

Winding resistance tests:

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%

Phase balance (or surge comparison) tests:

A surge comparison test will detect unbalanced windings, whether they are due to shorted turns or unbalanced circuits (which would result in circulating currents). Either of these problems will increase stator I^2R losses.

Perform this test after the rewind but before impregnation. 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. Identical traces for each phase indicate that the decay curves for all phases are the same and that the phases are thus identical. Two traces that do not appear identical indicate a fault that must be found by inspection.

Key points–phase balance/surge comparison tests

- ✓ 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.

<u>Ground test/hipot (high-potential) test as per IEEE Standard 1068, IEC 60034-2:</u>

<u>For windings rated above 250 volts, larger than 0.5 hp (.37 kW):</u>

- ✓ 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.

Note: For old windings, limit the hipot test voltage to 60% of the above test values.

A1.4. Measurements of Power - 3-phase AC circuit:

i) One wattmeter method:

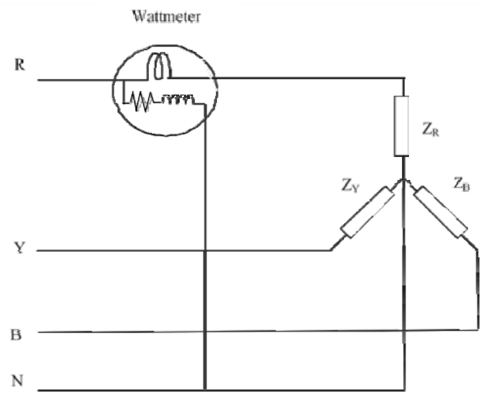


Figure 61; Single Wattmeter Method of Power Measurement in 3-Phase Circuit

For a balanced 3-phase load i.e. ZR = ZY = ZB, a single wattmeter may be connected into any one phase. This wattmeter will indicate the power in this particular phase only. Since the load is balanced, the total power in the 3-phase circuit will be given by:

Total power = 3 x Wattmeter reading

ii) <u>Two-wattmeter method</u> :

This is most the common method for measuring power in a 3-phase, 3-wire system since it can be used for both balanced (ZR = ZY = ZB) and unbalanced loads (ZR & ZY & ZB) connected in either star or delta. The current coils are connected to any two of the lines, and the voltage coils are connected to the other line, the one without a current coil connection.

Total power = W1 + W2

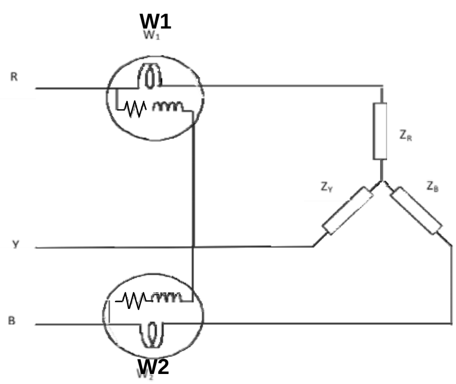


Figure 62; Two Wattmeter Method of Power Measurement in 3-Phase Circuit

iii) Three-wattmeter method :

If the installation is 4-wire and the load is unbalanced, then 3 wattmeters are necessary. The wattmeter's connection is shown in the below figure. Each wattmeter measures the power in one phase and the total power will be given by:

Total power = W1 + W2+ W3

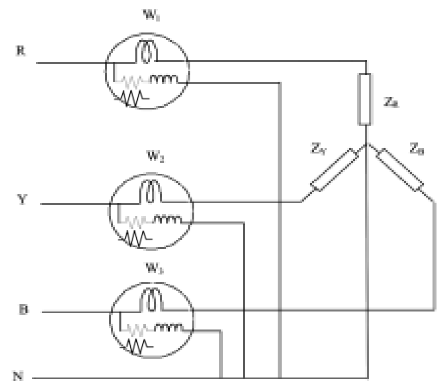


Figure 63; Three Wattmeter Method of Power Measurement in 3-Phase Circuit

A1.5. 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).

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. For example, if 3600 ampere-turns were required for a magnetization level of 85 kl/in2 (1.32T), and it was desired to limit the current through the loop turn lead wire to 80 amperes, then the loop turns required would be 45 (80 x 45 = 3600). The loop turns are typically wrapped close to each other, to maximize the area of the core that can be probed for hot spots.

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.
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.

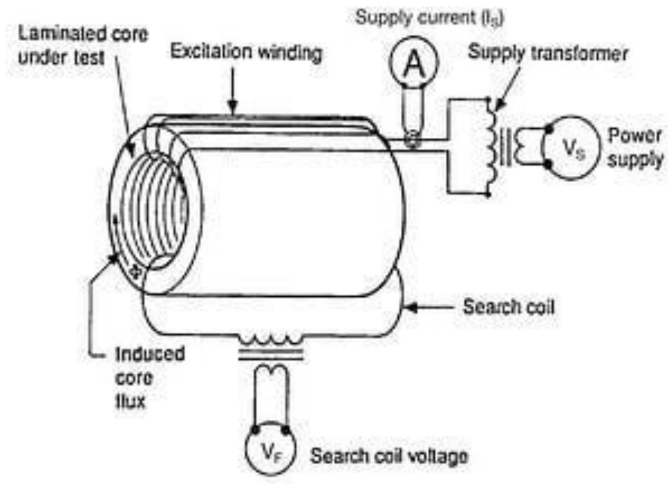


Figure 64; Core Test Configuration

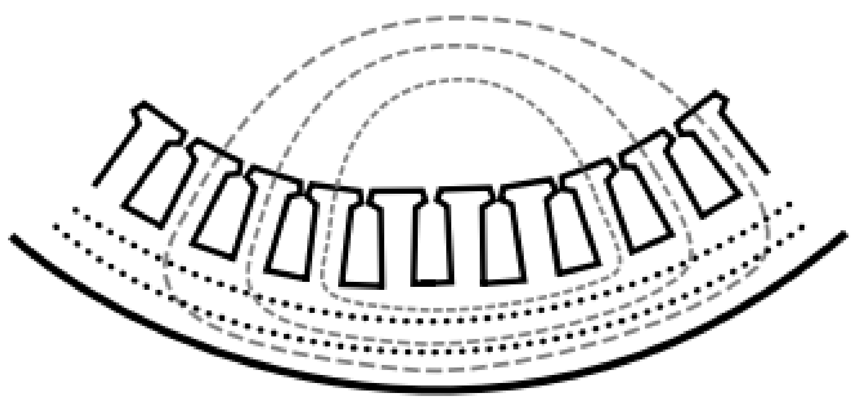


Figure 65; Flux induced by the machine's winding when the rotor is removed

The short dashed lines (- - -) depict flux paths created by the stator winding. The dotted lines (. . .) illustrate the flux paths of a 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 over the conventional loop test are primarily to 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. Further, the 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. Since the magnetic flux path is the same as that of the loop test, the core loss value indicated by the commercial device core test is not comparable to the core loss determined by the IEC 60034-2.

Figure 66; **Commercial core testers and Infrared core results**

Core test acceptance levels

Most manufacturers of commercial core testers suggest a test flux level of 85 kl/in2 (1.32T) in the core back iron. A potential drawback to this approach is that the core material may be approaching the “knee” of the magnetic strength versus the current curve–i.e., saturation. That being the case, a large increase in current might not result in a meaningful increase in magnetic flux, because the curve is just that, a curve, not a straight line. Since this condition can distort the results of a before and after core test, it is suggested that the tolerance on core loss after winding removal should not be more than 20%. That is, the core loss value after removing the windings, whether measured by conventional loop test or commercial tester, 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 1.32Tup to 1.5T is recommended for more than 20 minutes.

Annex 2. The needed Tools for Motors' Rewinding Workshop

Bench:

The working bank is made of a pinch of wood loaded on an iron base and fixed to it with screws, and the base has drawers used to store small hand tools that the technician needs during industrial operations. The working bank must be solid and of appropriate dimensions (length - width - height) so that the work can be done easily.

Bench Vice::

It is a means used to fix the artifacts to facilitate industrial operations on them. It is composed of a fixed jaw and a movable jaw. The fixed jaw is fixed in the jaw, and the movable jaw is moved by a hand connected to a screwed column called the wick. It moves inside a fixed body in the fixed jaw. The sickle is made of cast iron.

Electric Drill:

It is an electrically driven drill with a chuck ranging from 10 mm to 13 mm and sometimes up to 20 mm. There are types with different capacities (ranging from 350 watts to 2500 watts or more). The electric dredger can be either one speed, two speeds, or several speeds, and one or two directions.

Electric Drill Bits:

The bits are tools that are installed in the drilling machines to make the holes with it; Puncher tools are known for their diameter, degree of hardness, and the purpose for which it is used.

Electric Drill and Bits

Hammer:
Used to knock the chisel to cut the wires of old coils.

Chisel:
Used to cut off old coils.

Rubber Hammer (Mallet):
Rubber Hammer is used in the processes of bending and straightening the iron sheets, and it is made of wood or rubber, which is used in the processes of winding motors.

Center Punch:

It is used to mark the motor before disassembling it. The tip should be serrated with a sharp tip.

A Pair of Scissors:

It is used in electrical work to cut Press Pan paper and insulating cotton tape.

Pullers:

A puller is a tool used to remove parts such as bearings, pulleys, or gears from a shaft. They have legs, typically two or three which circle the back or inside of a part and they also have a forcing screw that centers up against the end of a shaft. The screw applies force to make removal simple and with little effort from the user.

Insulators Cutting Machine:
Used to cut the Press Pan Paper and then bends it on the machine before dropping it into the slots.

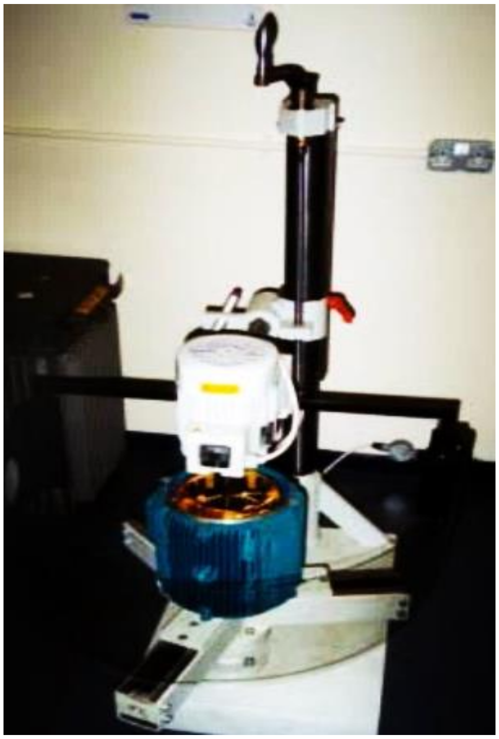
Winding Machine and Winding Heads:

The winding machine is manual or electrical, including modern types, automatic or semiautomatic. The winding heads allow the rewinders to achieve the required winding configurations.

Winding heads

Cut-off Machine:

Used to cut old coils without using a hammer and chisel to avoid damaging the iron heart.



Hydraulic Cut Off and Extraction Machine:

Used to cut and extract old coils in one step. It is usually used for large motors.

Controlled Temperature Burn-out Oven:

To burn and liquefy the varnish with temperature control without direct use of flame.

Vacuum Pressure Impregnation Oven:

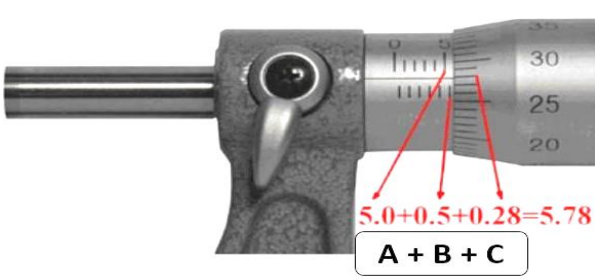
Used to penetrate and cover solvent-free epoxy resins.

Tachometer:

The tachometer is a device for measuring the speed of the number of revolutions of rotation RPM. It is used to measure the speed of rotation of the shaft (axis) and it is usually calculated by the number of revolutions per minute (RPM).

Micrometer:

The micrometer is used to measure wire diameters, coil diameters, and plate thicknesses. It is characterized by its higher accuracy, ease, and clarity of reading with it.



Screwdrivers:
Screwdrivers are used to loosen and fasten nails and are made of steel and have a hand that may be of wood, plastic, or bakalite, and there are different shapes and types in length and type, relative to their length of the 4,6,8,10,12 cm. As for its type, there isa regular screwdriver, a cross screwdriver, and a star screwdriver.

Spanner:
It is also called the ordinary key and it is made of hardened steel and has different sizes that fit each of it one or two sizes for the head of a bolt or a nut, they are in the form of sets.

The Peel :

Used to strip wires with diameter more than 0.5 mm.

Pliers:
It is made of steel and consists of two jaws. The shape of the jaw varies according to the type and shape of the pliers. Including the insulated and non-insulated. They are of many types, and the isolated ones are used in electrical circuits in bending, cutting, or peeling wires, loosening the inner and outer rings (clips), and holding the nuts, which are of different shapes and sizes.

Electric soldering Iron:
It consists of three parts, the first part is the head and is made of red copper, the second part is a hollow metal pipe installed at the top end of the head and inside this pipe, the third part is the electric heating coil and is made of nickel-chrome wire to heat the head, while the other end of the pipe has a soldering iron hand. It is made of insulating material, and the connecting wire with a plug is attached.

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