

# Good Practice Guide to

# Maintain Motor Efficiency

Based on the 2019 and 2003 Rewind Studies  
of premium efficiency, energy efficient,  
IE2 (formerlyEF1) and IE3 motors

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## Introduction

The purpose of this guide is to provide repair/rewind practices and tips that will help service centre technicians and motor winders maintain or increase the efficiency, reliability and quality of the motors they repair.

Some of the included procedures derive directly from the 2019 and 2003 rewind studies by EASA and AEMT of the impact of repair/rewinding on motor efficiency. Others are based on the findings of an earlier AEMT study [1998] of small/medium size three-phase induction motors and well-established industry good practices .

The procedures in this guide cover all three-phase, random-wound induction motors. Much of the guide also applies to form-wound stators of similar sizes.

**(Note:** This guide provides many specific procedures and recommendations. Alternative practices may accomplish the same results but must be verified.)

## Terminology

The terms used to describe horizontal and vertical induction motors in this guide are those commonly found in other EASA, AEMT, NEMA, IEC, IEEE, and ANSI documents. These terms are printed in bold type in Figure 1 and Figure 2 (Page 2), with alternate terms listed beneath them.

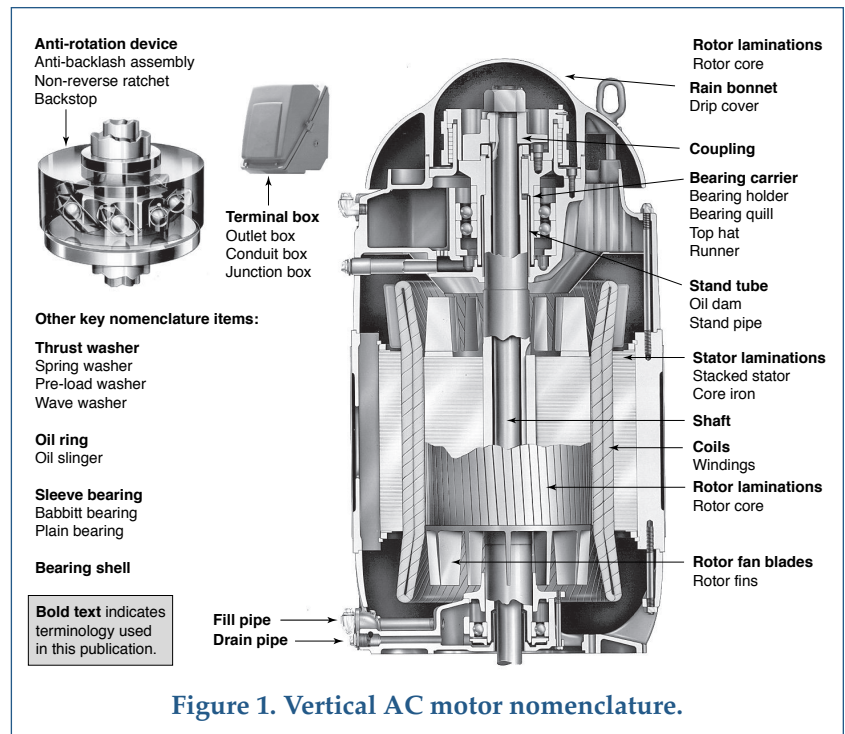


Figure 1. Vertical AC motor nomenclature.

## Energy losses in induction motors

There are five types of losses in an induction motor (see Figure 3, Page 2):

- Core losses in the stator and rotor
- Stator  $I^2R$  losses
- Rotor  $I^2R$  losses
- Friction and windage losses
- Stray load losses

The core, friction and windage losses do not significantly change with motor load, provided the motor is operated from a fixed voltage and

### WARNING: HAZARDOUS AREA MOTORS

Some elements of this *Good Practice Guide To Maintain Motor Efficiency*, particularly those concerning changes to windings, do not apply to hazardous area/explosion-proof motors (e.g., UL, CSA, IECEx). Do not use this guide for those types of motors.

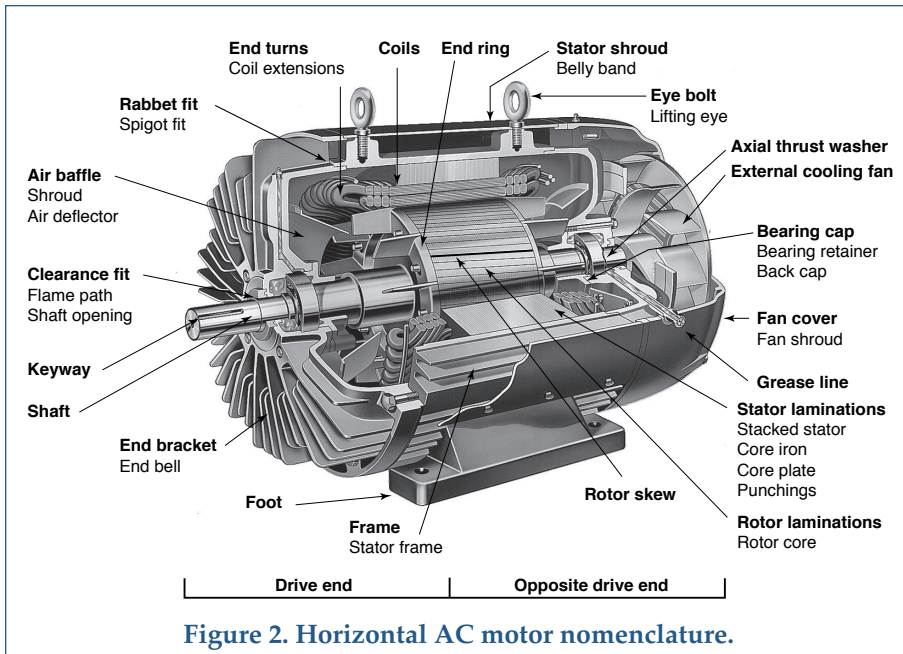


Figure 2. Horizontal AC motor nomenclature.

Figure 4 (Page 3) illustrates how the losses vary in relation to load for a typical 4-pole induction motor.

### Core (iron) losses

Core losses can increase if excessive pressure is applied to the stator core (e.g., by fitting a new stator frame with too small a bore). Damaging the interlaminar insulation (the very thin layer of insulation between each lamination in the stator and rotor core) can also increase core losses. This can happen if the stator is burned out at too high a temperature.

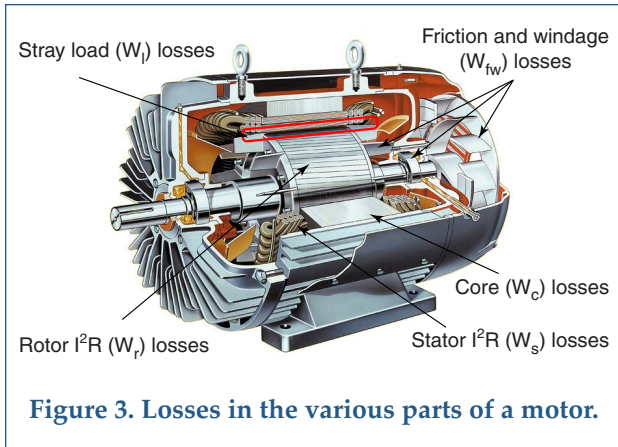


Figure 3. Losses in the various parts of a motor.

frequency. The  $I^2R$  and stray load losses increase significantly as load is increased.

Both core and  $I^2R$  losses (and particularly the rotor losses) may be higher when the motor is supplied from a variable-frequency inverter.

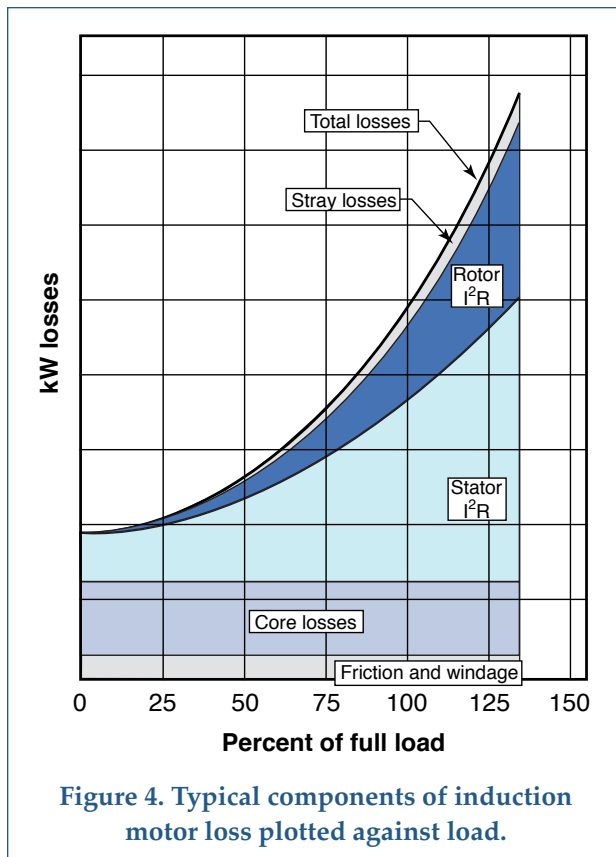
In many cases, losses can be decreased during the repair process by following good practice procedures.

Table 1 shows a breakdown of the averaged losses for the motors tested in the rewind studies.

TABLE 1. COMPARISON OF LOSS DISTRIBUTION BY PERCENT FOR MOTORS TESTED IN THE REWIND STUDIES

Losses	2003 2 pole average	2003 4 pole average	2019 4 pole average	Design factors affecting losses
Core losses ( $W_c$ )	19%	21%	22%	Electrical steel, air gap, saturation, supply frequency, condition of interlaminar insulation
Friction and windage losses ( $W_{fw}$ )	25%	10%	11%	Fan efficiency and airflow volume, lubrication, bearings, seals
Stator $I^2R$ losses ( $W_s$ )	26%	34%	34%	Conductor area, mean length of turn, heat dissipation
Rotor $I^2R$ losses ( $W_r$ )	19%	21%	19%	Bar and end ring size and material, amount of slip
Stray load losses ( $W_l$ )	11%	14%	14%	Manufacturing processes, slot design, air gap, condition of air gap surfaces and end laminations

Note: The single 2 pole motor in the 2019 study was not listed since it would not be a statistically valid sample quantity.



The following factors affect the quality of the laminations:

- Core and tooth rigidity and ability to hold shape
- Damage caused by the failure
- Quality of the interlaminar insulation (core-plate)
- Damage caused by burnout
- Damage caused by coil removal
- Excessive grinding and filing

**Burnout process.** The stator core is composed of laminations—thin pieces of steel coated with insulation to reduce eddy-currents in the core. Assuming the failure did not blow a hole in the core (thereby reducing its mass) or fuse lamina-

tions together, the next concern is to burn out the windings at an appropriate temperature.

The interlaminar insulation may be an organic, chemical or oxide coating. Newer motors are likely to have C-5 (inorganic) lamination insulation that can withstand higher temperatures than that of older motors. Because winding insulation materials degrade at lower temperatures than the interlaminar insulation, the burnout process—properly done—will not harm the interlaminar insulation.

The burnout oven should be fitted with a chart-recorder to document that each motor is burned out at a safe temperature. The temperature probe should be attached to the stator core during the burnout process.

Tight control of the burnout process is essential. Burning out at a temperature significantly below 680°F (360°C) may not entirely break down the insulation on the old winding. In that case, it will take more force to remove the coils and slot insulation, which may damage to the core (e.g., splayed teeth) and increase the stray load losses.

Burning out at more than 750°F (400°C), however, increases the risk of damaging the interlaminar insulation and may increase the core losses, especially if the interlaminar insulation is organic or otherwise susceptible to high burnout temperatures. Some other lamination insulation processes (e.g., oxide steam-bluing, some waterborne and some organic varnishes) require extreme caution and may not be suitable for burnout.

All satisfactory results in the rewind studies were achieved with a burnout temperature of 700°F (370°C), with the temperature measured at the tooth area of the stator core.

**Loading cautions for burnout ovens.** Do not stack stators in the oven; the temperature of the stators on top may be increased by the burning stators underneath. Do not place stators in the oven with the bores vertical; this is especially critical with aluminium frames.

**Core losses.** Due to the wide variety of electrical magnetic steels in use, it is impossible to set rigid rules for core loss test acceptance. However, measuring core loss before burnout and after core stripping and cleaning will identify significant increases in core losses. If the core loss test losses increase by more than 20%, consider replacing the motor. In special cases, consider restacking or replacing the laminations.

**Electrical steel considerations.** The ability to maintain motor efficiency or to minimize any depreciation in efficiency is influenced by the quality of the stacked stator core and its laminations.

The motor industry uses such a wide variety of electrical steels that it is difficult to generalize their characteristics. The most common considerations include:

- Fully processed vs. semi-processed steel.
- Carbon vs. silicon steel.
- Grain orientation—induction motors use non-oriented electrical steel.
- Hysteresis and eddy current losses ranging from 1.5 to 6 watts/lb (3.3 to 13.2 watts/kg).
- Thickness ranging from 0.014" to 0.035" (0.4 to 0.9 mm).
- Interlaminar insulation materials ranging from C-0 to C-6. Most modern motors use C-5.

### Special issues for electrical steels

- Semi-processed steels are usually good candidates for oven burnouts.
- Safe burnout temperature depends on the interlaminar insulation.

Differences among world steel standards complicate this discussion, but the type of the interlaminar insulation is the key issue. When in doubt about the kind of interlamination insulation a motor has, the safest course is to contact the motor manufacturer.

It also is important to remember that:

- Thin laminations with narrow or unsupported teeth are more susceptible to tooth distortion.
- Laminations with significant damage and hot spots may not be good candidates for rewind, particularly when efficiency and reliability are major considerations.

For more information, see the earlier discussion of the "Burnout process."

### Stator I<sup>2</sup>R losses

The stator I<sup>2</sup>R losses are often the largest component of loss. In motors of 45 hp (30 kW) and above tested in the rewind studies, the average stator I<sup>2</sup>R losses were 31% of the total loss (range 22 - 47%). Consequently, anything that affects stator I<sup>2</sup>R losses can have a significant impact on the efficiency of a repaired / rewound motor.

Stator I<sup>2</sup>R losses can be reduced by increasing the

**TABLE 2. EFFECT OF CHANGES TO THE END TURN LENGTH ON TYPICAL TEFC/IP54, 460V DESIGNS**

HP/kW	Poles	End turn length	Full load efficiency (%)	Total losses (watts)	Change in total losses (%)
50/37	4	10% short	93.1	2746	-2.8
		Nominal	93.0	2825	
		10% long	92.8	2911	3.0
100/75	4	10% short	94.9	4020	-2.6
		Nominal	94.8	4129	
		10% long	94.6	4243	2.8
200/150	4	10% short	95.6	6921	-2.5
		Nominal	95.5	7099	
		10% long	95.3	7278	2.5
50/37	2	10% short	92.7	2935	-2.9
		Nominal	92.5	3024	
		10% long	92.3	3122	3.2
100/75	2	10% short	93.9	4881	-3.3
		Nominal	93.7	5047	
		10% long	93.5	5212	3.3
200/150	2	10% short	95.1	7697	-2.3
		Nominal	95.0	7875	
		10% long	94.9	8075	2.5

conductor cross-sectional area and/or decreasing the mean length of turn (MLT). Changing the winding configuration can increase the stator I<sup>2</sup>R losses, although some changes (e.g., increasing the cross-sectional area) will reduce them.

Table 2 (Page 4) contains the results of an earlier EASA study that show the impact on efficiency of a 10% change in end turn length (about a 5% change in MLT) for typical TEFC (IP54) motors. Where it was feasible, reducing the MLT improved the efficiency over the nominal value. From this it is clear that end turn length and MLT are critical to motor efficiency.

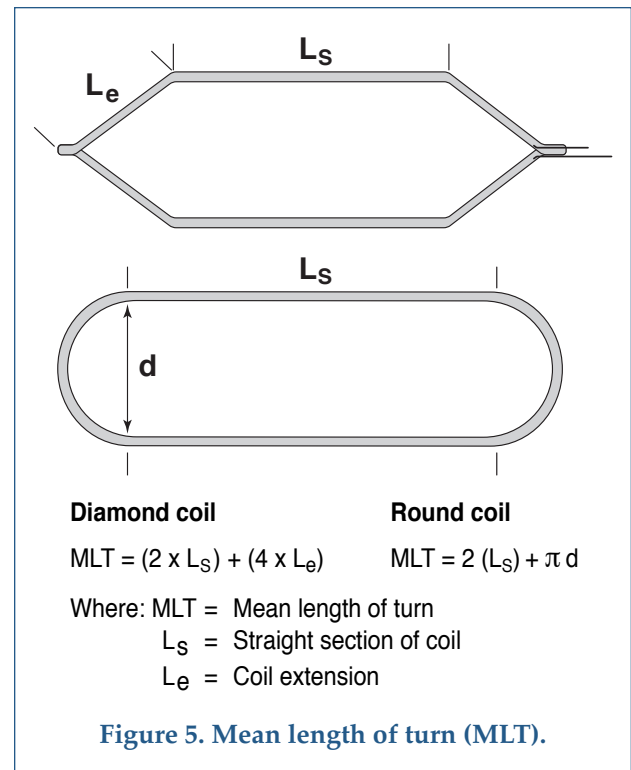
**Mean length of turn (MLT).** Allowing the MLT (Figure 5) to increase will increase stator I<sup>2</sup>R losses and therefore decrease motor efficiency. Conversely, decreasing the MLT where possible will reduce stator I<sup>2</sup>R losses to help maintain or even improve efficiency. The goal is to reduce the straight section of the coil where it exits the slot to the minimum required to avoid mechanical strain on the slot cell. Whatever coil shape is used, make sure the coil end turns are no longer than those of the original winding.

Avoid reducing the MLT too much. Doing so could make the stator difficult or even impossible to wind. It may even affect cooling, in extreme cases causing the winding temperature to rise.

## Rotor losses

Rotor losses should remain unchanged, unless the rotor was damaged during the failure or its diameter was changed by machining. Rotor losses will increase if the flux density is reduced as a result of a change to the stator winding or if rotor cage (bars and end-rings) resistance is increased. They also can increase due to change/damage to rotor conductors of a squirrel cage motor.

Taking a skim cut of the rotor can also affect rotor losses. Machining the rotor diameter (skim cutting) to increase the air gap can reduce losses at the expense of power factor; however, too great an increase in air gap will increase losses. Service centres should avoid this procedure. (If a rotor is



machined during each of several repairs, sooner or later the air gap will become a problem. The repair history of motors is rarely known, so most service centres are reluctant to machine the rotor diameter.)

## Friction and windage losses

The friction and windage losses can be increased by:

- Badly fitted bearings, excessive interference fits.
- The addition or use of incorrect seals, lack of seal lubrication, or damage to shaft surface (lip seals) or end bracket surface (face seals).
- Installing an incorrect replacement fan.
- Over-greasing the bearings.

**Fans.** External fans are another potential source of efficiency loss. Windage varies among fan designs, depending on factors like diameter, the number and size of blades, material, and surface



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finish. The most important variable, however, is fan diameter.

All else being equal, a fan with a smaller diameter moves considerably less air  $[(D2/D1)^5]$  than one with a larger diameter. That means it takes more energy to drive a fan having a larger diameter. As an example, it would take 28% more power to drive an otherwise identical replacement fan whose diameter is 5% larger than the original. That diverted power is lost power, which reduces motor efficiency.

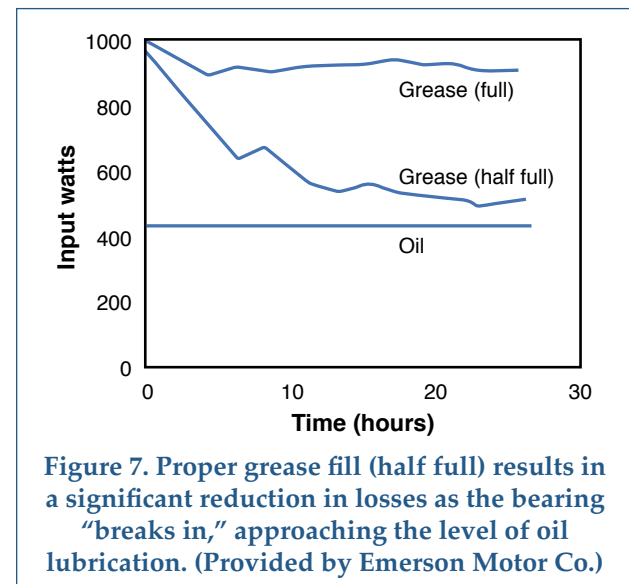
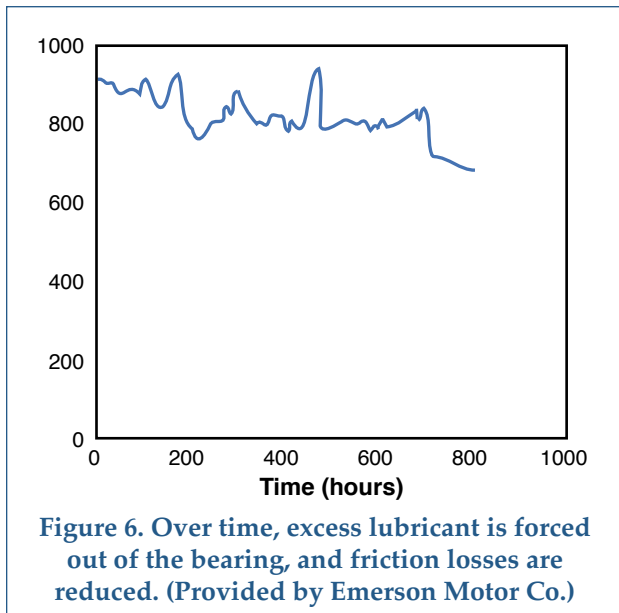
It is good practice to use an identical replacement for a damaged fan. Substituting a nonidentical fan may change the efficiency of the motor. Of course, if chemical processes or other considerations make the original fan design impractical, discuss alternatives with the motor manufacturer to avoid adversely affecting efficiency.

It is also important to keep air passages clear—i.e., the ducts and channels in the frame or core through or over which cooling air passes. Wholly or partially blocked ducts or channels may reduce friction and windage loss, but the reduced cooling effect will increase other losses—particularly stator  $I^2R$  loss—much more. This can lead to early failure as well as reduced operating efficiency.

**Bearings.** Bearings of C-3 internal clearance are the standard for most electric motors. A bearing with a contact seal can create more friction than a shielded, open or non-contact sealed bearing. The increased friction results in a slight drop in efficiency. To avoid degrading efficiency, it is good policy to use the open bearing style installed by the manufacturer.

Lubrication intervals, quantity and viscosity will also impact the efficiency of an electric motor. Follow the manufacturer's guidelines for each motor to maintain motor efficiency. The 2003 rewind study found that over greasing a bearing, even by a small amount, increased the friction losses by about 500 watts for some larger motors. Excess lubrication not only reduces efficiency; it also causes local overheating, which can shorten bearing life dramatically.

When the application and environment call for the reliability of sealed bearings, expect some increase in bearing temperature and friction losses. A better alternative may be to install non-contact seals or bearing isolators, which exclude contaminants without causing friction. Some bearing manufacturers also offer non-contact sealed bearings.



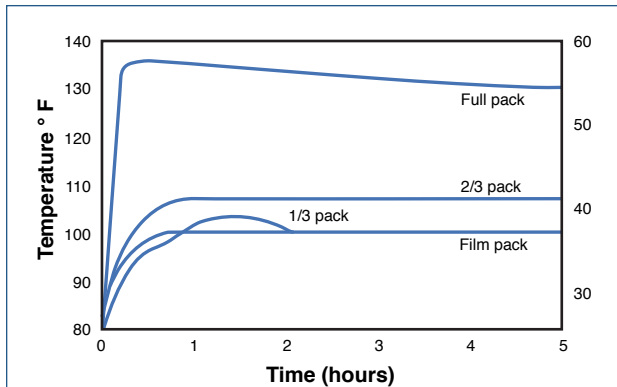


Figure 8. Short-term “break in” periods may not be adequate to reduce bearing losses, regardless of fill, as illustrated here. (From *Lubrication Fundamentals*, 1st ed. by Mobil Oil Corp.)

**Impact of too much bearing grease.** Several studies have found that over-greasing the bearings can increase friction losses (see Figure 6 and Figure 7 on Page 6 and Figure 8). For the 2003 rewind study, grease was added to the bearings of two rewind test units in Group A. No change in lubrication was made on the rest of the motors in the test. As expected, bearing friction on the over-greased motors increased and efficiency dropped 0.3 to 0.5%. Figure 9 illustrates the decrease in losses over time for one of the 60 hp (45 kW) motors in the 2003 rewind study.

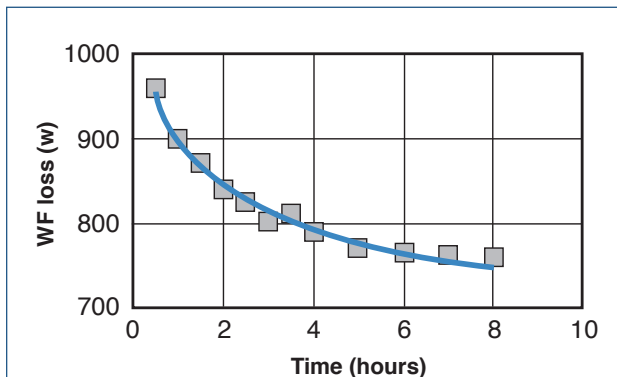


Figure 9. Reduction in F & W losses during the break-in run for a 60 hp (45 kW) motor with proper grease fill tested in the 2003 rewind study.

## Stray losses

Stray load losses are typically 10 - 20% of total motor loss. The high frequency harmonic fluxes that occur near the air gap surfaces of the stator and the rotor core are a major source of stray loss. These are caused by magnetic interaction of the stator and rotor teeth.

Stray loss can increase if the air gap surfaces of the laminations are smeared together (e.g., by mechanical damage, excessive filing or grinding, etc.). Stray loss will also increase if the air gap is uneven (i.e., stator and rotor not concentric) or if the rotor core is axially displaced relative to the stator (e.g., if the shaft is replaced and the rotor core is incorrectly positioned).

**Stray loss analysis.** The stray load losses for the motors in Group A of the 2003 rewind study increased significantly. The cause was the mechanical damage done to the stator core (i.e., splayed ends of lamination teeth) in removing the old windings and slot insulation. This in turn increased the pulsating or zigzag losses (see Figure 10, Page 8).

The burnout temperature for the motors in Group A was 660°F (350°C), which is too low to completely break down the old winding insulation. As a result, it took excessive force and extra cleaning to strip out the old windings. The resultant mechanical damage increased stray load losses.

The burnout temperature for motors in Groups B, C and D of the 2003 rewind study was increased to 680 - 700°F (360 - 370°C). This broke down the old insulation more completely, making it easier to remove the windings and clean the slots. Since lamination teeth were not damaged in the process, the stray load losses did not increase.

## Summary of factors that can increase motor losses

Listed below are factors that can affect the different energy loss components in induction motors.

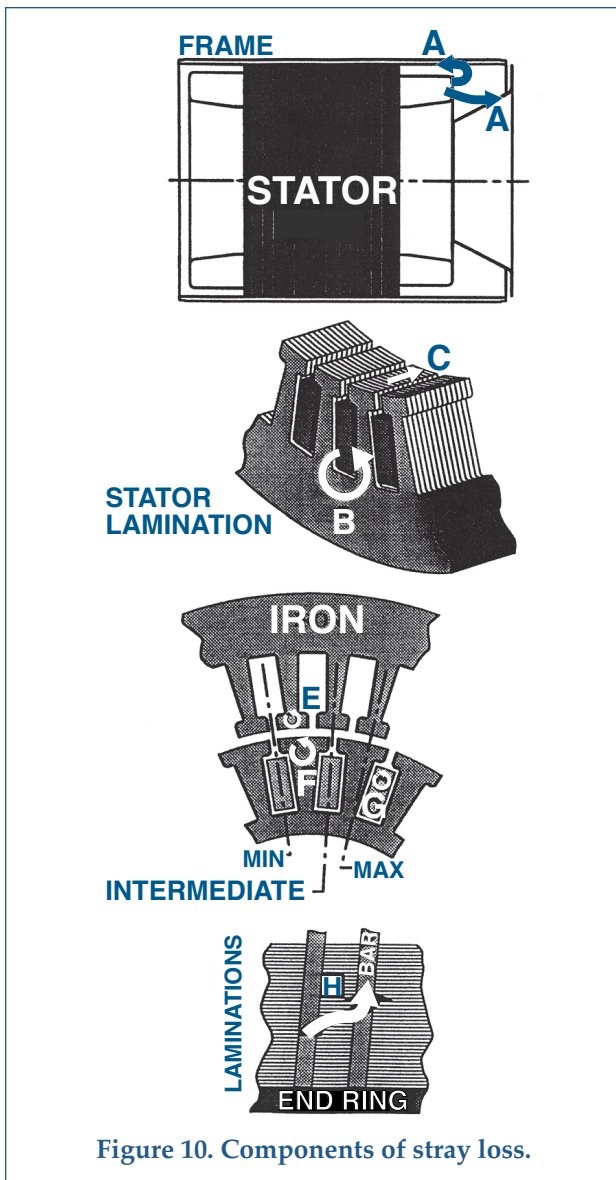


Figure 10. Components of stray loss.

### Stator core losses

- Flux density change
- Excessive radial or axial pressure on core
- Excessive heating during burnout (i.e., damage to interlaminar insulation)
- Type of coreplate used (some coreplates cannot withstand normal burnout temperature—e.g., steam blued)

- Mechanical damage to core (e.g., splayed lamination teeth, smeared laminations)

### Stator I<sup>2</sup>R losses

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

### Rotor losses

- Change to end ring cross section
- Change/damage to rotor
- Machining the rotor
- Flux density change (e.g., due to stator winding change or replacing magnetic steel shaft with non-magnetic material)

### Friction and windage losses

- Changes to bearings
- Changes to seals
- Changes in lubrication
- Changes to fan(s)
- Changes to air passages
- Changes in operating temperature

### Stray loss

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

## 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.

### Key points

The main motor repair processes include:

- Preliminary inspection
- Dismantling the motor
- Documenting and removing the old winding and cleaning the core
- Rewinding the motor
- Mechanical repairs
- Reassembling the motor

The following sections provide good practice procedures for each stage of the repair process.

## 1.0 Preliminary inspection

The preliminary inspection forms an important part of the complete motor repair record and may yield vital clues about the cause of failure. It is important to include all data sources on a data card like the ones shown in Figure 11 and Figure 12 (Page 10). In particular, record the following information:

### Key points

- Motor nameplate(s) data
- Results of external inspection
- Customer input

### 1.1 Motor nameplate(s) data

- Record all the data on the nameplate (see Figure 13 and Figure 14 on Page 11). Some codes, numbers or letters which seem meaningless may be very important if it is necessary to

HP/kW	RPM	Poles	Manufacturer	
SLOTS		TYPE		VOLTS
COILS		MODEL		AMPS
GROUPING		STYLE		PHASE
TURNS/COIL		AUX.DEVICE	EFF.	HERTZ
WIRE SIZE		LEAD LENGTH	# LDS	FRAME
WIRES IN MULTIPLE		DEG C RISE	DUTY	DEG C AMB
PITCH: 1 TO		SERIAL #		INS CLASS
CONNECTION		ENC TYPE		SVC FCTR
JUMPER		COIL	DENSITIES:	CMA
CORE LENGTH				AMM <sup>2</sup>
CORE ID				AGD
BACKIRON				THD
SLOT DEPTH				BID
TOOTH WIDTH				
LBS WIRE				
JOB NUMBER				
CUSTOMER				

Figure 11. Original polyphase AC winding data sheet.

**AC Winding Particulars**

---

**Customer:** \_\_\_\_\_

**Maker:** \_\_\_\_\_

**Serial No:** \_\_\_\_\_ **Model:** \_\_\_\_\_ **Enc:** \_\_\_\_\_

HP/kW                                  V                                  A                                  RPM

Section	Stator Rotor		Checked by	PRE-VARNISH TESTS		
	Existing	New				
Core Length				WINDING RESISTANCE TO EARTH		
Core Diameter						
No. Slots						
No. Coils				RESISTANCE PER PHASE		
Turns/Coil						
Sections/Coil						
Size of Conductor				PRESSURE TEST TO EARTH		
No. Cond. in //						
Slot Depth						
Tooth Width				PRESSURE BETWEEN PHASES		
Back Iron Length						
Coil Pitch						
Weight of Coil				STATIC TEST <span style="float: right;">Y/Δ</span>		
Winding Type				TEST VOLTAGE		
Slots/Pole/Phase						
Coil Groups				amps	amps	amps
No. // Circuits				POLARITY CHECK		
Connections						
CE Projection						
NCE Projection				OTHER TESTS		
Insulation Class						
Lead Section						
<b>DIAGRAMS OR OTHER DETAILS</b>          				DATA TAKEN BY:  WINDINGS COMPLETED BY:  CHECKED AND PASSED BY:  DATE:		

Figure 12. Original polyphase AC winding data sheet.

CATALOG #		MODEL #	
<input type="radio"/> SHAFT END BRG	<input type="radio"/> OPP END BRG		<input type="radio"/>
FR	TYPE	ENCL	
PH	MAX AMB	°C	ID#
INSUL CLASS	DUTY	WT	BAL
HP	RPM	SF	HZ
VOLTS	MAX KVAR	NEMA NOM EFF	
AMPS	CODE	DES	
SF AMPS	PF	GUARANTEED EFF	

Figure 13. NEMA motor nameplate with efficiency rating.

<input type="radio"/> AC MOTOR IEC 60034		<input type="radio"/> IE3		<input type="radio"/>
TYP	SER. NO.		YEAR	
KW	r/min	V	A	HZ
KW	r/min	V	A	HZ
DUTY	INSUL	AMB	°C RISE	K DESIGN 3 PHASE
COS Ø	CODE	IP	IC	SERVICE FACTOR
GREASE	DE BRG		NDE BRG	
DIAG	I <sub>A</sub> /I <sub>N</sub>	M <sub>A</sub> /M <sub>N</sub>	kg MOTOR WT	
CE				

Figure 14. IEC motor nameplate with IE3 efficiency rating.

contact the manufacturer for parts or information. Taking a digital photo of the nameplate helps assure that all data on it is accurately recorded.

- Remember that there may be more than one nameplate. Some OEMs fit their own nameplates (which sometimes replace those installed by the motor manufacturer), and some repairers add a plate indicating the motor has been repaired previously.
- Check whether the motor is energy efficient (IE2) or premium efficiency (IE3)

## 1.2 Results of external inspection

Look for and record:

- General condition—old/new, dirty/clean, etc.
- Cooling air ducts clear/obstructed—may have caused overheating (see Figure 15).
- Shaft discoloured (brown/blue)—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.

## 1.3 Customer input

Customers may be able to provide:

- Operating environment—temperature, vibration, etc.
- Type of driven equipment.
- How many hours/day motor runs.
- Approximate motor load.
- How often it is started.
- The type of starter used.
- Whether the motor has been rewound before.
- How long the motor has operated since new (or since last rewind).
- Unusual events—e.g., power outage, lightning



Figure 15. Motor with blocked cooling fins.

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strike, water damage, problem with driven equipment, etc.

- Power supply and starting
  - Across line/direct on line
  - Soft start
  - Part winding start
  - Inverter
  - Wye-delta/star-delta

### 2.0 Dismantling the motor

Sometimes it is obvious from its outward appearance that the motor is not repairable and that a new one must be supplied. More often, however, the motor must be dismantled before this decision can be made. 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. 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.

#### Key points

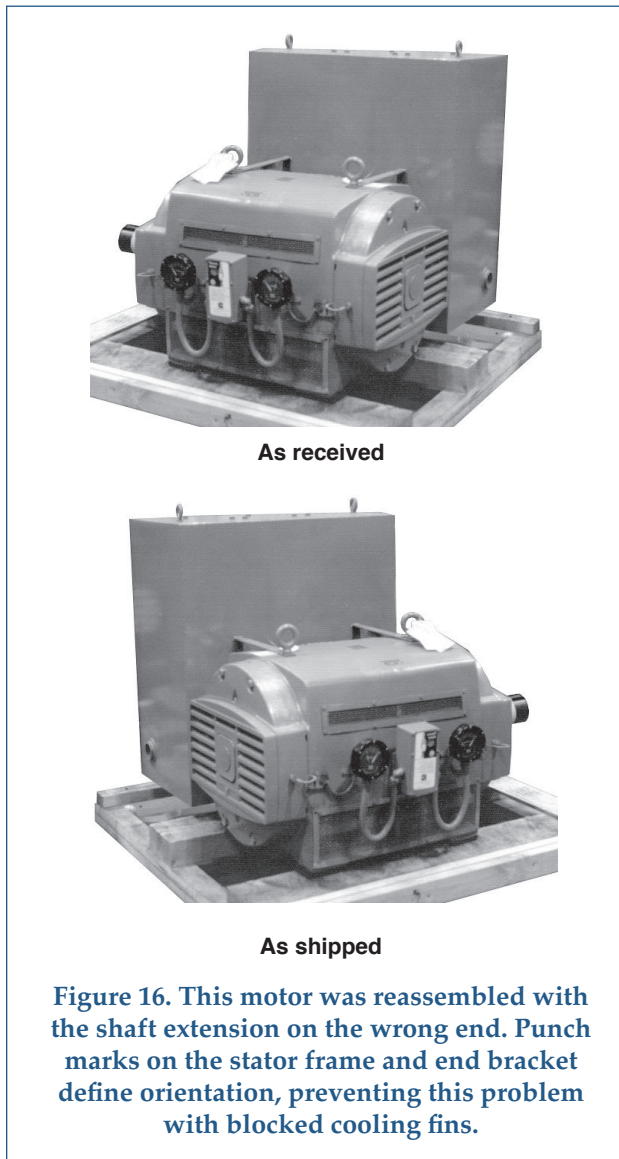
- Terminal box position, layout and connections
- Orientation of end brackets and bearing caps
- Bearing sizes, types and clearances
- Axial position of rotor relative to stator (drive end or opposite drive end)
- Orientation of shaft with respect to the main terminal box
- Careful rotor removal to prevent damage to air gap surfaces or winding
- Internal inspection
- Mechanical damage to components or signs of misuse
- Motors with contamination

### 2.1 Terminal box layout and connections

- Record markings on both winding leads and terminals.
- Record positions of any links between terminals (make sketch).
- Check that insulation on winding leads imme-

diately 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 lug size and style.



## 2.2 Orientation of end bracket and bearing caps

End brackets and bearing caps should be installed in exactly the same positions as originally fitted. Orientation of the grease ports should place the inlet at or near the top of the bracket to assure proper relubrication. Therefore, indelibly mark all end brackets and stator frames at both ends of the motor (e.g., by punch-marking the components with a centre punch) before dismantling the motor (see Figure 16, Page 12).

## 2.3 Bearing sizes, types and clearances

Most motors have a ball bearing at each end. Some may have a roller bearing at the drive end to increase the radial load capacity, or thrust bearing(s) for high axial loads. Always fit new bearings of the same type as those removed, unless they were misapplied.

The following items are critically important in bearing selection:

- Bearing enclosure
- Fit and tolerance
- Precision class
- Internal clearance
- Load application
- Type of lubricant

## 2.4 Axial position of rotor relative to stator (drive end or opposite drive end)

The rotor should be centred axially within the stator core. If it is displaced axially, centering forces will exert pressure on the bearings. If it is displaced beyond the end of the stator core, magnetizing current will increase. Note position of axial thrust washer when dismantling the motor (i.e., DE or ODE).

## 2.5 Orientation of shaft with respect to the main terminal box

Document the mounting position of the shaft in relation to the leads (e.g., NEMA F1 or F2, IEC IM B3). There are many ways to do this. Some repairers describe this as “leads left facing shaft” or “shaft right facing leads.”



Figure 17. Rotor removal using a rotor removal tool.

## 2.6 Careful rotor removal to prevent damage to air gap surfaces or winding

The rotor presents a considerable overhung load when one end bracket has been removed. Allowing it to scrape along the stator bore during rotor removal can damage the air gap surfaces of both stator and rotor and increase losses. Winding damage can also result. An effective way to remove and replace rotors in horizontal motors is by using a rotor removal tool (see Figure 17).

## 2.7 Internal inspection

Look for and record:

- Water or dirt ingress
- Condition of stator and rotor cores—damage or overheating
- Condition of winding—discolouration, type of failure

### 2.7.1 Water or dirt ingress

Loose dust, water marks or rust on internal surfaces, particularly in the bottom of the motor, may have been caused by water or dirt ingress, which can contribute to failure. However, on totally enclosed (TE) or totally enclosed fan cooled (TEFC) machines, water marks or rust can be caused by condensation of the air inside the machine as it cools down.

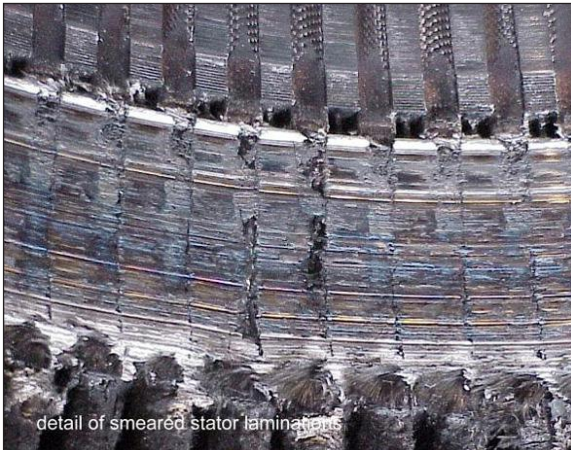


### 2.7.2 Condition of stator and rotor cores—damage or overheating

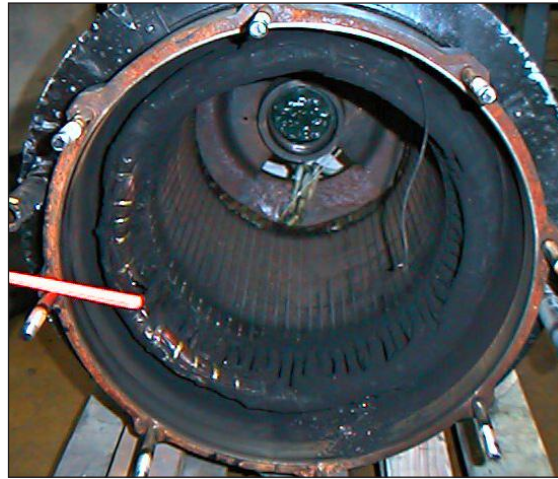
The stator and rotor cores may have been damaged in a number of ways, including the following:

- **Core rub**, often due to failure of one of the motor bearings or rotor pullover caused by excessive radial load. This smears the air gap surfaces of the laminations together and can increase eddy current loss. Depending upon the extent of the damage, the motor may not be repairable.
- **Major mechanical damage** to either the stator or rotor core. Pieces missing or fused together may sometimes be caused by a major electrical fault, such as a short circuit inside the slots. Any application with an ungrounded system or poor ground fault protection is particularly prone to this type of damage. If such damage has occurred, weigh its effect on motor efficiency and performance when considering a repair (see Figure 18).

**Serious overheating of the stator or rotor cores.** If the interlaminar insulation is damaged, eddy currents will increase, causing excessive iron losses (see Figure 19).



**Figure 18. Major mechanical damage to the stator bore; not repairable unless the core is restacked or replaced.**



**Figure 19. Overall discolouration of the stator winding—usually indicates excessive temperature. Check load, power supply and cooling.**

**Note:** Eddy current losses follow a square law with respect to heating—i.e., if the eddy current doubles, the heating effect increases four times. Therefore, a small increase in eddy current loss can have a large effect on motor temperature and efficiency. Serious overheating of the core is sometimes evident from discoloured wedges, topsticks or air gap surfaces that may range from light straw to various shades of blue, depending upon the temperature reached.

### 2.7.3 Condition of winding—discolouration, type of failure

Overheating of the winding does not normally constitute irreparable damage, but the repairer should carefully inspect the windings and try to determine the cause of failure.

A winding that is evenly discoloured at both ends may indicate a failure due 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 warranty period offered by the repairer.

Most winding failures have many possible causes, and diagnosing these is beyond the scope of this guide. For more information, consult EASA's book *Root Cause Failure Analysis*. Excellent photographs of different types of winding failure also are available in the EASA brochure "Failures in Three-Phase Stator Windings."

### 2.8 Mechanical damage to components or signs of misuse

Mechanical damage may affect motor performance. Look for:

- Damage to the fan or fan cover
- Damaged or blocked cooling ducts/channels/ribs
- Fans or air baffles incorrectly located or missing
- Shaft discolouration adjacent to either bearing (overload or misalignment)

### 2.9 Motors with considerable contamination

If the exterior is packed full of contaminants, address maintenance procedures or consider a different enclosure. If the winding is packed full of contaminants, the enclosure may not be suitable for the operating environment.

### 3.0 Removing the old winding and cleaning the core

There are four elements to this task:

- Recording the winding details on appropriate data cards or sheets (see Figure 11, Page 9, and Figure 12, Page 10)
- Core loss testing
- Removing the old winding
- Cleaning the stator core in preparation for rewinding

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.

### 3.1 Recording the winding details

It is important to record the full details of the old winding accurately and permanently (see Figure 11 on Page 9 and Figure 12 on Page 10). It is a good idea to collate all the winding data gathered over time into a winding data bank. The data to record are listed in the key points; the following explanatory notes may also be helpful.

Document the appropriate fields to ensure that the winder can duplicate the winding, and the engineer can confirm its suitability.

**Note:** If the motor has been rewound previously, the winding may not be the original and may not be the correct one for the motor. Try to verify observed data from another source (e.g., your own data bank, the EASA database or the manufacturer).

#### Key points—recording the winding details

- 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
- Grouping
- Coil pitch(es)
- Connections
- Coil extension/overhang—connection end
- Coil extension—non-connection end
- Number and size of wires in each coil

### 3.2 Core loss testing

The best safeguard against burnout-related problems is to perform a core loss test before burnout

and after the core has been stripped and cleaned. Commercial core loss test equipment can simplify the process, or a loop test (also called a “ring flux test”) can be performed using the procedure in the *EASA Technical Manual*.

Commercial core loss testers can give an indication of whether or not the stator core losses have been affected by the winding removal process. They normally will not record the same core loss as would be measured during a load test on the same machine. 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 tester at the same setting is always used for each test on a given core.

### Key points—core loss testing

- Conduct all tests using the same core tester.
- Make sure the tests are conducted within the manufacturer’s recommended operating range for the tester being used.
- Carry out tests:
  - Before burnout
  - After the core has been cleaned prior to re-winding.
- Remember that figures obtained are comparative, not actual losses.
- If the core loss increases by more than 20% (see Table 3):
  - Make sure the settings of the core loss tester have not been changed and repeat the test.
  - If the repeat test confirms the increased loss, repair the core or consider replacing it.

### 3.3 Removing the old winding

The stripping process can directly affect motor efficiency. If the stator laminations are damaged

**TABLE 3. LEVELS (IMPACT) OF CHANGES IN CORE LOSSES**

Levels	Change in core loss, %
None to slight	Not measurable
Threshold of measurement	20% increase
Moderate	40% increase
Consequential	60% increase
Significant	80% increase
Major	100% increase
Excessive	>100% increase
Catastrophic	>200%

Reference: CSA C392:20, Table A.1.

during coil removal [e.g., teeth splayed (flared), end laminations buckled from excessive force or heat, etc.], the core losses and stray losses will increase. To avoid this, burn out the core at sufficient temperature to break down the winding insulation fully, so the coils can be removed without undue force.

#### 3.3.1 Step 1—Cut off one coil extension (usually the opposite connection end)

Cut off the coil extension of the winding as close to the stator core as possible without damaging the stator core. Cutoff machines are available commercially for this purpose (see Figure 20, Page 17). Regardless of the method used to cut off the coil extension, be careful not to damage the laminations.

#### 3.3.2 Step 2—Remove the old stator winding

If removing the windings requires excessive force or damages the laminations, the burnout process was not done at a suitable temperature or time duration. The best step at this point is to repeat the burnout cycle.

#### 3.3.3 Core damage caused by overheating

The coils must be heated sufficiently to burn out the old insulation from the windings without



**Figure 20. Winding cut off machine.**

damaging the interlaminar insulation of the stator core. The temperature required depends on the type of insulating varnish used, with epoxy resins usually requiring the highest temperature.

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 interlaminar insulation can be damaged if the stator core gets too hot, resulting in increased iron losses and reduced motor efficiency.

All satisfactory results in the rewind studies were achieved with a burnout temperature of 700°F (370°C).

### **3.3.4 Burnout using a controlled temperature burnout oven**

The varnish and the insulation must be broken down before the windings can be removed from the stator core. This is commonly done with a controlled temperature burnout oven.

A distinct advantage of this method is that it provides a tightly controlled burnout process. Properly done, it ensures that the stator core will not reach a temperature that could damage the interlaminar insulation. It is important to set the oven temperature to monitor the temperature of the stator core, and to follow the oven manufacturer's instructions regarding cleaning and safety (see Figure 21).



**Figure 21. Controlled temperature burnout oven.**

**Loading cautions for burnout ovens:** Do not stack stators in the oven; the temperature of the stators on top may be increased by the burning stators underneath. Do not place stators in the oven with the bores vertical because the cores may shift; this is especially critical with aluminum frames.

### 3.3.5 Removing the old winding

When the heating process is complete and the stator temperature is safe to work with, pull out the old winding, taking care not to damage the core (e.g., by splaying the end teeth outwards).

When removing the coils, pull them away from the bore at a slight angle to keep the conductors from snagging or bending the end laminations. If a coil is difficult to remove, reduce the possibility of damage by applying uniform pressure to the teeth spanning it. (Remember, splayed teeth will increase stray losses.)

Burning out a core at too low a temperature often increases stray losses due to the physical damage inflicted on the core when the coils are removed. Burning out the stator at sufficient temperatures will prevent this problem. In addition, safe burnout temperatures will not increase eddy current losses because they will not damage interlaminar insulation.

**Note:** If removing the windings requires excessive force or damages the laminations, the burnout process was not done at a suitable temperature. The best step at this point is to repeat the burnout cycle.

### Key points—removing the old windings

- Cut off one coil extension using a winding cutoff machine.
- Burn out old insulation at appropriate temperature in a controlled-temperature burnout oven set to monitor core temperature.
- Do not overheat the core.
- Remove the winding without damaging the core.

- **Caution:** Some motors may have the connection brought out on both coil extensions.

### 3.4 Cleaning the stator core

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. If the teeth of the laminations at the end of the core have been pulled outwards (splayed) during coil removal, reposition them with minimum force.

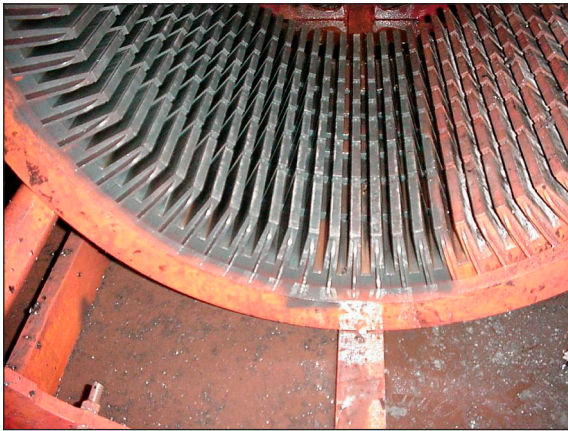
#### 3.4.1 Core preparation

Keep filing and grinding to the minimum required to correct damaged areas. Removal or shorting of laminations will increase core losses. Unless corrected, severe core damage due to motor failure (e.g., rotor rub resulting from a failed bearing) will decrease motor efficiency. Carefully weigh this against the customer's need to return the motor to service. In some cases, repair may be a stopgap measure until a replacement motor can be obtained.

#### 3.4.2 Methods of removing slot insulation

Of the various ways to remove insulation from the slots following burnout, these methods proved to be satisfactory in the rewind studies:

- **Careful scraping** using a sharp knife to separate the remaining pieces of slot liner material from the core.
- **High-pressure washing** using a commercial/domestic high-pressure washer after which the core must be baked dry (see Figure 22, Page 19).
- **Abrasive blasting** using mildly abrasive material such as walnut hulls, crushed corncobs or plastic beads. Blasting with more abrasive materials like sand, crushed flint, ceramic pellets or even glass beads may cause surface shorting of the laminations, which increases core and stray losses.
- **Wire brushing** using a medium/soft wire brush.



**Figure 22.** This core has been partially cleaned by using a high-pressure washer to remove the slot insulation debris.

Avoid using files or grinders to remove slot insulation. These can smear the laminations together and increase eddy current losses near the air gap surfaces of the core.

### 3.4.3 Damaged teeth at the end of the core

Sometimes teeth on the end laminations are splayed 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.

### 3.4.4 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. In the case of rotor drag, using a bore sander to scrub the affected area before burnout is advisable.

If the damaged area is not extensive, the effect on losses or efficiency should not be significant. In cases of relatively minor damage, bumping the affected area axially will usually improve things. (This is sometimes called “watt-knocking, since it “knocks” the watts out of the core.) If this does not work, use a sharp knife to separate the lami-

nations in the damaged area and treat them with insulating material (coreplate) of an appropriate temperature rating. Insulating varnish may also seep between the separated laminations when the new winding is impregnated, helping to restore the interlaminar insulation.

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 reduced. The best solution in such cases is to replace the core, or to dismantle, reinsulate and rebuild it.

### Key points—cleaning the stator 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 medium/soft wire brush.

### After cleaning the slots:

- Reposition damaged teeth
- Repair minor damage to air gap surfaces
- Replace or reinsulate and rebuild cores if major damage has occurred.

## 4.0 Rewinding the motor

In choosing a replacement winding the repairer has two options:

- Copy (duplicate) the winding already in the motor (provided it has the manufacturer’s original data).
- Choose a different style of winding that will perform as well as or better than the original.

Most repairers can redesign motors to make them more energy efficient. Most of the time, however, the best way to maintain motor efficiency is to duplicate the original winding, while increasing the copper cross sectional area as much as possible and keeping the end turns as short as possible

(certainly no longer than those of the original winding). Note, though, that in some designs, the coil extension is critical for heat dissipation. If it is too short, the temperature of the winding may rise, causing  $I^2R$  losses to increase.

When production volume justifies the cost, motor manufacturers use automatic coil winding and inserting machinery to produce motors with concentric coil groups (see Figure 23). Repairers often find lap windings much quicker and easier to install (see Figure 24). This section therefore sets out the basic rules (in terms of maintaining efficiency) for just two types of rewind:

- A “copy” (or duplicate) rewind
- Changing the original concentric winding to a conventional lap winding

### 4.1 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 using EASA’s *Motor Rewind Database* software. If the repairer has a winding data bank, this may provide useful information as well.

There are other clues, however. 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 centres also try to prevent future failures of the motors they rewind by upgrading the coil bracing, insulation systems, etc.

### 4.2 Copy (duplicate) rewinding

If the details of the old winding have been recorded (see Section 3.1, Page 15), and provided that

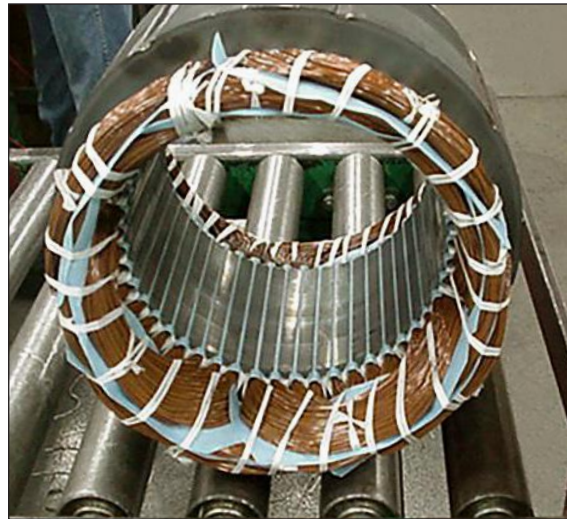


Figure 23. Typical concentric winding.

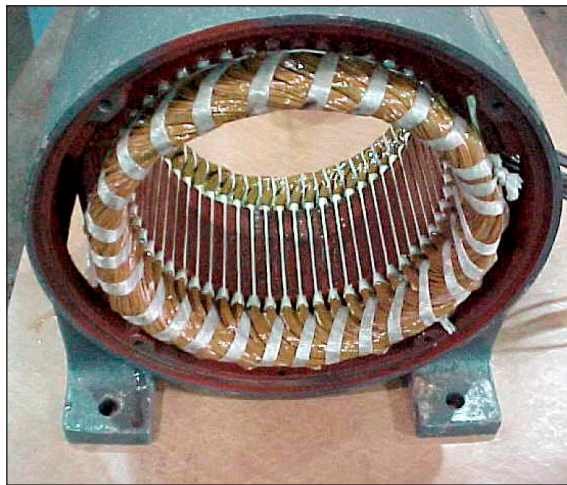


Figure 24. Typical lap winding.

it is the manufacturer’s original winding data, 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 rewind motor:

- Minimize the length of the coil extensions.

- Increase the copper cross-sectional area per turn.

### 4.2.1 Mean length of turn (MLT)

It is important that the mean length of turn (MLT) of the new winding is not greater (preferably less) than that of the old winding. Otherwise, the new winding will have higher resistance than the original and therefore higher  $I^2R$  losses (see Figure 5, Page 5). When energy efficiency is the primary consideration, do not convert from concentric to lap without first calculating the MLT for both windings and confirming that the total winding resistance will be lower.

The distance around the coil also changes with the span. A wider span requires a longer conductor—the additional length times the turns per coil. A longer conductor has greater resistance, so the total winding resistance partly depends on the coil span(s) selected.

The coil extension—the distance the winding protrudes past the core on each end—also affects the conductor length. The MLT can be controlled by careful fitting when the coils are made. The shorter this length, the lower the total winding resistance, which in turn increases the efficiency. With careful fitting, a diamond coil requires a shorter MLT than a round nose coil. While the difference in length is slight (about 3 - 7% less length in the end turn area), any decrease in resistance is beneficial.

### 4.2.2 Minimize the length of the coil extensions

The coil extensions consist of “inactive” copper that merely connect 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  $I^2R$  losses. It is therefore important to keep the coil extensions as short as possible. If the MLT of the rewind exceeds that of the original, the  $I^2R$  losses will increase. Attention



Figure 25. Typical coil extension for a 4-pole motor.

to the following rules will prevent this:

- Keep the coil extensions (see Figure 25) within the measured dimensions of the original winding.
- Do not extend the slot cell 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 reduce the copper losses of the manufacturer’s original winding. Record the coil dimensions of the new winding.

### 4.2.3 Winding resistance and heat dissipation

Likewise, careful fitting usually can produce a winding with lower resistance than the original. Lower resistance reduces the  $I^2R$  losses, making the motor more efficient. All else being equal, a



carefully fitted rewound motor can be of higher efficiency than the original. As a general practice, the service centre should replace the stator winding with an exact duplicate of the one it removed. That means the same wire size, winding type, turns, span and coil extension.

Be careful to not increase the coil length to make the windings easier to install. That will increase total winding resistance. Increasing the coil extension also will increase total winding resistance.

As mentioned earlier, when energy efficiency is the primary consideration, do not convert from concentric to lap without first calculating the MLT for both windings and proving that the total winding resistance will be lower.

When comparing lap and concentric windings, also consider the exposure of each coil to the air stream that cools the windings. Each coil of a lap winding has the same exposure to airflow, unlike the layers of a concentric winding that vary in their ability to dissipate heat. Avoid “buried coils” (see Figure 26), which tend to shorten insulation life and sometimes prevent good varnish impregnation. These drawbacks can apply to the middle layer of a 3-tier concentric winding. When copy-winding a 3-tier concentric winding, inserting the coils in the same manner as a lap winding balances the cooling effectiveness.

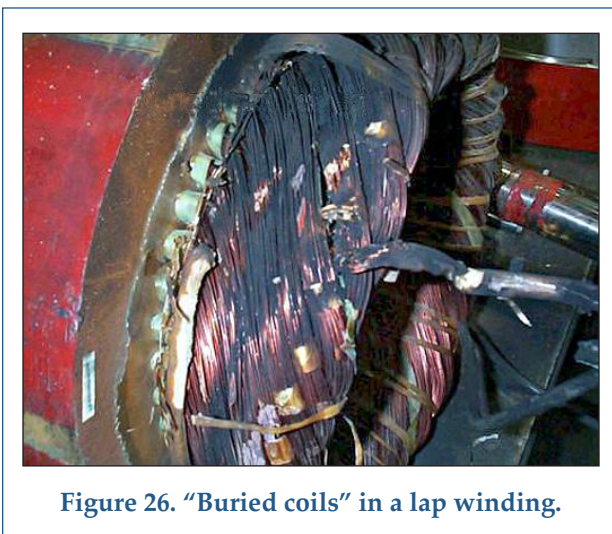


Figure 26. “Buried coils” in a lap winding.

### 4.2.4 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 (IE2) and premium efficiency (IE3) 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—copy rewinding

- Check that the old winding has manufacturer’s original data, if available.
- Use the same winding configuration.
- Keep the coil extensions as short as practical.
- Keep the length of the coil extension the same (preferably less).
- Use the same coil pitch (or pitches).
- Use the same turns/coil.
- Use the same (preferably larger) copper cross-sectional area per turn.
- Use the same or shorter MLT.

Doing the above should maintain or reduce the (temperature corrected) winding resistance.

### 4.3 Changing to a two-layer lap winding

Assuming no stator or rotor damage, and no reduction in the circular mils/amp, the potential efficiency of the motor should remain unchanged by the repair process. The next consideration is the winding type.



**Figure 27. Typical concentric coil group. Note that each coil has a different span.**

When production volume and economics justify it, manufacturers prefer using concentric windings (Figure 27), which can be machine-wound and require less labor. This benefits purchasers by keeping the cost of new motors economical. The drawback is that the turns in each coil of a concentric winding are not equally effective.

Service centres that use predominantly hand-winding methods normally find it easier to use lap windings because the coils are all the same (see Figure 28). (It takes a winder only slightly longer to manually insert a lap winding than a 2-layer concentric winding, and about the same insertion time as a 3-layer concentric.)

Lap windings are acceptable if the new winding has the same flux/pole as the original—with one exception. A 2-pole concentric winding should be maintained because an equivalent lap winding would require a very wide pitch and be difficult to insert.



**Figure 28. Lap winding showing all coils with the same span.**

Single-layer lap windings are sometimes used for small- to medium-size motors, because the coils are easier to insert and no separators are required. This allows more room for copper. However, the use of single-layer (full slot) lap windings should be avoided for 2-pole motors, as they often suffer from poor performance due to harmonics.

Double-layer lap windings distribute flux through the core better than single-layer lap windings. Replacing a double-layer lap winding with a single-layer lap 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). For more information and more detail on how to redesign a winding, see the *EASA Technical Manual*.

#### Advantages

- Efficiency can be maintained or improved. Except for a 2-pole concentric winding, the double-layer lap yields the best results.

- 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 magneto motive force (MMF) curve more closely resembles a sine wave.
- Phase insulation and coil bracing are more likely to be uniformly placed.

### Disadvantages

- Usually none, provided that the conversion is done correctly.
- For further information, see the *EASA Technical Manual*.

### 4.3.1 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:

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

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 the purposes of a rewind (other than for a different voltage or frequency)  $E$  and  $f$  are constants.

That leaves three variables under the control of the repairer:

- $N$  - the number of series turns/phase
- $K_d$  - the winding distribution factor
- $K_p$  - the chord factor (pitch factor)

The product of these variables must remain constant to satisfy equation (1) above, 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.

### 4.3.2 Effect of winding type and design on motor performance

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  $K_p$  and  $K_d$  such that fundamental EMF's per coil are maximized and harmonic EMF's minimized.

Although this complex subject is outside the scope of this guide, there are some basic rules that may help service centre personnel:

- Double-layer windings (two coils per slot) give better results than single-layer windings.
- Some coil arrangements (notably skip slot) give much worse results than conventional double-layer lap or consequent-pole windings.
- Full-pitched coils generate higher harmonic EMF's than short-pitched or over-pitched coils.
- In general, double-layer, short-pitched lap windings give the best results. Single-layer, short-pitched lap windings are sometimes used on small/medium size machines but should

never be used to replace a double-layer lap winding.

#### 4.4 Completing the winding

After fully inserting the winding, connect the coils and leads to match the original connections exactly (if a copy or duplicate rewind) or appropriately for the replacement lap winding. Use connection leads that are as large as practical and mark all of them correctly per the applicable NEMA or IEC standards. Brace the coil extension either as the manufacturer’s original winding or better (i.e., more rigid).

#### 4.5 Winding tests

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

##### 4.5.1 Winding resistance tests

When the stator is fully wound, measure and record the resistance of each phase (or between leads) as well as the ambient temperature. For future comparison or for comparison to manufacturer resistance data, correct the resistance to a common reference temperature (normally 25°C) using the formula:

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

Where:

$R_x$  = corrected winding resistance

$T_a$  = ambient air temperature

The resistance of each phase or between leads should be within 2% of the average for random lap windings and may be higher for concentric windings (see Figure 29). A high resistance between leads could indicate a high-resistance connection joint. An open stator test in conjunction with thermography should reveal the faulty connection.

##### 4.5.2 Phase balance (or surge comparison) test

A surge comparison test will detect unbalanced windings, whether they are due to shorted turns



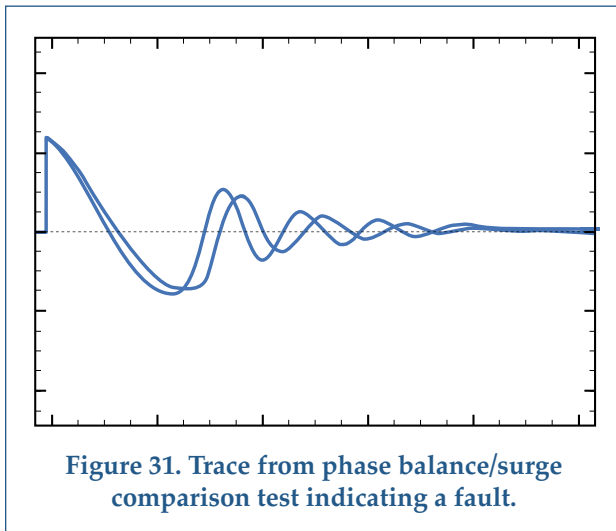
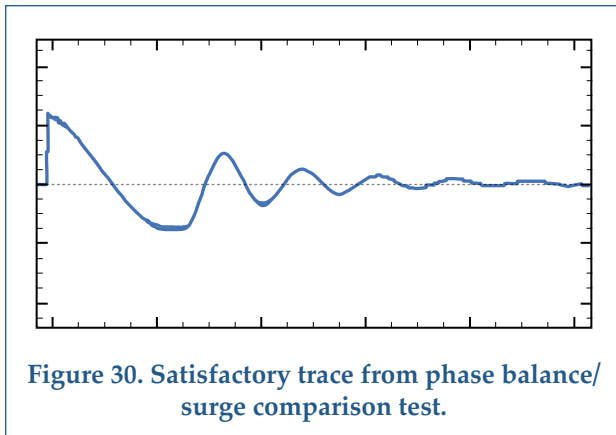
Figure 29. Measuring the resistance of a coil group. Note the meter leads are clamped securely to bare conductors; also note the ambient temperature thermometer.

or unbalanced circuits (which would result in circulating currents). Shorted turns will result in winding failure, and unbalanced circuits will increase stator  $I^2R$  losses.

Perform this test after the rewind but before varnish 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 2 phases of the winding, or sequentially for all 3 phases, and recording the voltage decay on an 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 (see Figure 30 and Figure 31 on Page 26).

##### Key points—phase balance/surge comparison tests

- Perform on completed winding before varnish impregnation.
- The test compares the decay rate of identical voltage pulses applied simultaneously for 2 winding phases or sequentially for all 3 phases.



- The trace pattern indicates the phases are identical (okay—identical traces) or different (fault—traces do not match).
- The trace pattern gives guidance to type of fault (see equipment manufacturer’s guide).

### 4.5.3 Ground test/hipot test

For windings rated above 250 volts, larger than 0.5 hp (0.37 kW):

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

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 80% of the test voltages given above. Subsequent tests should not exceed 65% of the test voltages given above.

**Note:** For reconditioned windings, limit the hipot test voltage to 65% of the above test values.

### 4.6 Winding treatment

Impregnating the winding with varnish and subsequently air drying or baking the varnish until it is cured serves several purposes:

- It provides a mechanical bond between conductors.
- It increases the dielectric strength of the insulation.
- It protects the winding from moisture and contamination.
- It fills the air spaces between conductors (particularly in the slots).

The last property is important in terms of motor efficiency since it helps transfer the heat generated in the conductors more easily to the stator core and frame, and thus keeps the winding temperature down. The varnish impregnation process should be carefully controlled to minimize voids and maximize slot fill. Poor impregnation results in increased winding temperatures, and therefore increased resistance and lower efficiency.

Lower winding temperature = lower resistance  
= lower  $I^2R$  losses

#### 4.6.1 Varnish and resin types and classifications

Insulating varnishes and resins are classified by long-term temperature withstand capabilities and types of material.

Most modern varnishes and resins are Class F or H (155°C or 180°C). It is important to use a varnish or resin of at least Class F, even if the motor is of a lower insulation class (e.g., Class B,

130°C), to compensate for hot spots or unusual load conditions.

Depending on the treatment used, the goal is to fill the voids among conductors as completely as possible. Avoid a large buildup of material, however, and remove excess varnish or resin from the bore before placing the stator in the bake oven. Also, if the stator is to be impregnated, follow the varnish or resin manufacturer's instructions for pre-heating.

### 5.0 Mechanical repairs that can affect motor efficiency

#### 5.1 Repairs to cores

##### a) Stator

- Grinding damaged surfaces of the core.
- Using undue force to reposition splayed teeth.
- Reducing the number of laminations.
- Improper restacking.

##### b) Rotor

- Grinding the surface.
- Machining the rotor with a blunt tool or at incorrect surface speed (i.e., smearing laminations together).
- Excessive air gap
- Failure to detect or properly repair broken rotor bars or end rings.

#### 5.2 Shaft repairs

- Failure to machine rebuilt bearing seats to the correct size for the bearings.
- Shaft replacement using material with different magnetic properties than the original.

#### 5.3 Housing repairs

- Repairs to stator frame or end bracket rabbet/spigot fits that reduce stator/rotor concentricity.
- Failure to machine a rebuilt bearing housing to the correct size for the bearing, and to concentricity with the stator bore.

- Fitting a new stator frame onto the stator core with a fit that is too tight (increases rotational losses in the core) or too loose (inhibits heat transfer from the core, increasing stator winding losses).
- Failure to clear blocked airways or cooling ducts.
- Failure to repair broken cooling ribs, or to replace missing ones.

#### 5.4 Bearings and seals

- Selecting incorrect bearings.
- Installing bearings incorrectly.
- Incorrect bearing lubrication (wrong grease, mixed greases, too much grease).
- Fitting the wrong type of seal.
- Fitting seals incorrectly.
- Failure to lubricate (or poorly lubricating) seals.

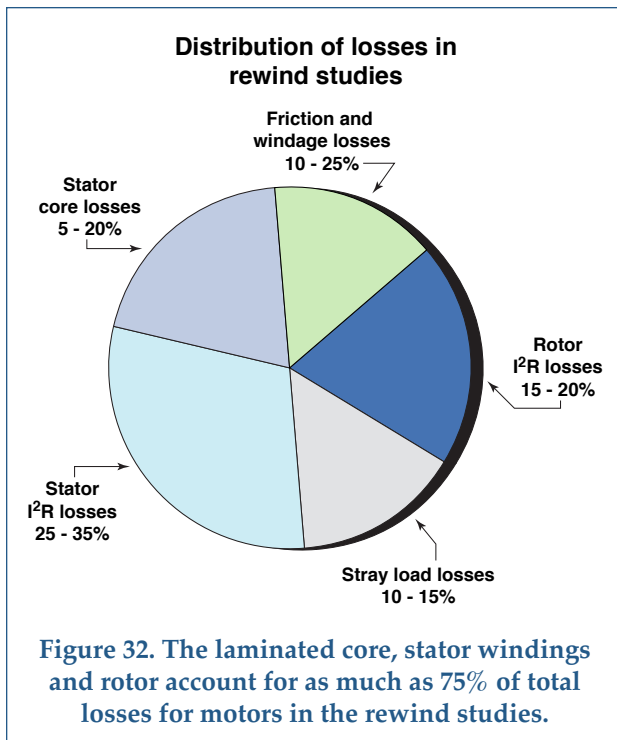
#### 5.5 Fans and fan covers

- Installing an incorrect fan, or locating the fan or fan cover in the wrong position (improper clearance between the fan and fan cover).
- Not replacing a damaged fan (i.e., missing/broken blades).
- Installing an incorrect fan cover.
- Not replacing a broken (damaged) fan cover.
- Not ensuring that the fan inlet is free from dirt or other material that might reduce airflow.

### 6.0 Reassembling the motor

Certain steps of the assembly process can impact the motor's efficiency. (**Note:** Figure 32 on Page 28 summarises the distribution of losses for the motors in the rewind studies.)

- **Bearing lubrication.** A critical step in motor assembly is to check the amount of grease in the bearing cavity. Depending on cavity design, shaft-to-bracket clearances and grease viscosity, the motor may have to run 8 hours or longer to purge enough excess grease to reduce friction



losses. Consequently, it is impossible to predict how long it will take a particular motor to normalize friction losses.

- **Thrust washers.** Particularly in cases where the bearing is tight in the housing, the assembly process may actually preload the bearings, increasing friction loss until the motor has thermally cycled several times. Running the motor for extended periods without full load will not alleviate this condition, as thermal expansion of the shaft is minimal until the motor approaches full-load operating temperature. Ensure that the thrust washer is installed correctly.
- **Fans and air baffles.** Placement of the external fan (of TEFC/IP 54, IP 55 motors) can affect the cooling effectiveness and therefore the winding resistance. For ODP (IP 11, IP 12) motors, the relative position of rotor fan blades and the air baffles is also likely to affect winding temperature. Leaving the air baffles out of the reassembled motor can have a significant

effect on the cooling system. Directional fans, of course, must be mounted correctly for the direction of rotation.

- **Handling.** Physical damage to the rotor or stator air gap surface may increase the stray-load losses. Rough handling can also damage the rotor or stator air gap surface, which could even increase the respective core losses.
- **Painting.** Finally, make sure ventilation openings do not get clogged when the motor is painted. While this may seem a small point, it is especially possible when rodent screens are installed over the openings.

### 7.0 Confirming the integrity of the repair

Load testing is not always practical, considering setup time, test time, and power consumption. Fortunately, it is relatively easy to confirm the integrity of the repair by checking for changes in the biggest loss components—core losses, stator I<sup>2</sup>R losses, and rotor I<sup>2</sup>R losses (see Figure 32).

- Comparison of before and after burnout core tests proves whether or not the core losses have changed. An increase of more than 20% should be a cause for concern.
- An accurate resistance measurement verifies any change in stator I<sup>2</sup>R losses if the original resistance is known. An increase of more than 3% should be a cause for concern.
- Rotor I<sup>2</sup>R losses should remain unchanged unless the rotor was damaged during the failure or its diameter was changed by machining.

That leaves windage, friction and stray losses.

- Windage will not change unless the fan is modified or changed. That is easy to avoid.
- Friction should not change if identical bearings (and seals if appropriate) with appropriate fits are used. Substituting sealed bearings for open bearings will increase friction. Avoid over-greasing bearings for the same reason.
- Stray losses are difficult to quantify, but one area where the repair process can impact them

is during the coil removal. Splayed lamination teeth will increase stray losses. The more force it takes to remove the coils, the greater the likelihood that teeth will be splayed. To avoid this, burn out stators at sufficient temperature to fully break down the insulation and allow for easy coil removal. All satisfactory results in the rewind studies were achieved with a burnout temperature of 700°F (370°C), measured at the stator core.

**Caution:** Some lower grade insulation processes, such as steam-bluing and waterborne or lower grade organic varnishes, require extreme caution and may not be suitable for burnout.

### Bibliography

- ANSI/EASA Std. AR100-2020: *Recommended Practice for the Repair of Electrical Apparatus*. Electrical Apparatus Service Association, Inc. St. Louis, MO, 2020.
- BS EN IEC 60034-23:2019: *Repair, Overhaul and Reclamation of Rotating Electrical Equipment*.
- The Effect of Repair/Rewinding on Premium Efficiency/IE3 Motors: Full Report*. EASA, Inc. St. Louis, MO, 2020.
- IEC Std. 60034-2-1: *Rotating Machines—Part 2: Methods for Determining Losses and Efficiency for Rotating Electrical Machinery From Tests (Excluding Machines for Traction Vehicles)*. International Electrotechnical Commission. Geneva, Switzerland, 2014.
- IEEE Std. 112-2017: *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2017.
- NEMA Stds. MG 1-2016 (Rev. 2018): *Motors and Generators*. National Electrical Manufacturers Association. Rosslyn, VA, 2016.



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