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CONTENTS

FIGURES

TABLES

1. INTRODUCTION

This Work Instruction provides the Eskom requirements for the refurbishment and repair of electric motors for power stations.

2. SUPPORTING CLAUSES

2.1 SCOPE

This Work Instruction covers the requirements for the stripping and assessment, redesign of weak features, general updating of design in accordance with modern design practise, rewinding, repair, impregnation, inspection, testing and certification of repaired motors.

2.1.1 Purpose

This Work Instruction provides Eskom requirements for the refurbishment and repair of electric motors for power stations, and acts as a Work Instruction to engineers and station personnel when involved in the process of refurbishing electric motors.

2.1.2 Applicability

a. The requirements of this Work Instruction are applicable to all Eskom Divisions that utilise electric motors in their plants.

b. Low Voltage motors rated at 1 000 V and below shall be rewound / repaired to the latest SANS 10242-1 standard.

2.1.3 Exclusions

While this Work Instruction contains quality control and assurance requirements, it does not cover all material and workmanship issues that shall be addressed by the *Repairer* through a duly certified ISO 9001:2008 Quality Management System.

a. This Work Instruction is applicable primarily to induction motors and does not fully cater for the requirements of Synchronous machines and other specialty designs such as Boiler Circulating Pumps and Nuclear environment machines.

2.2 NORMATIVE/INFORMATIVE REFERENCES

The following standards contain provisions that, through reference in the text, constitute requirements of this specification. At the time of publication the editions indicated were valid. All standards are subject to revision and parties involved in refurbishment processes based on this specification are encouraged to apply the most recent revisions of the standards listed below. Information on currently valid national and international standards may be obtained from the Information Centre at Megawatt Park. Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001, *Quality Management Systems.*

[2] BS EN 50209:1999, *Test of insulation of bars and coils of high-voltage machines.*

[3] BS 2757 *Method for determining the thermal classification of electrical insulation*

[4] IEEE Std 522 *IEEE Guide for Testing Turn Insulation of Form-Wound Stator Coils for Alternating-Current Electric Machines.*

[5] SANS IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

[6] SANS IEC 60034-2, *Rotating electrical machines – Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles)*

[7] SANS IEC 60034-2A, *Rotating electrical machines – Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles) – First supplement: Measurement of losses by the calorimetric method*

[8] SANS IEC 60034-3, *Rotating electrical machines – Part 3: Specific requirements for turbine-type synchronous machines*

[9] SANS IEC 60034-4, *Rotating electrical machines – Part 4: Methods for determining synchronous machine quantities from tests*

[10] SANS IEC 60034-5, *Rotating electrical machines – Part 5: Classification of degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification*

[11] SANS IEC 60034-6, *Rotating electrical machines – Part 6: Methods of cooling (IC Code)*

[12] SANS IEC 60034-7, *Rotating electrical machines – Part 7: Classification of types of construction, mounting arrangements and terminal box position (IM code)*

[13] SANS IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation*

[14] SANS IEC 60034-9, *Rotating electrical machines – Part 9: Noise limits*

[15] SANS IEC 60034-10, *Rotating electrical machines – Part 10: Conventions for description of synchronous* machines

[16] SANS IEC 60034-11, *Rotating electrical machines – Part 11: Built-in thermal protection. Chapter 1: Rules for protection of rotating electrical machines*

[17] SANS IEC 60034-12, *Rotating electrical machines – Part 12: Starting performance of single-speed three-phase cage induction motors*

[18] SANS IEC 60034-14, *Rotating electrical machines – Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher – Measurement, evaluation and limits of the vibration*

[19] SANS IEC 60034-15, *Rotating electrical machines – Part 15: Impulse voltage withstand levels of rotating a.c. machines with form-wound stator coils*

[20] SANS IEC 60034-16-1, *Rotating electrical machines – Part 16: Excitation systems for synchronous machines: Chapter 1: Definitions*

[21] SANS IEC 60034-16-2, *Rotating electrical machines – Part 16: Excitation systems for synchronous machines: Chapter 2: Models for power system studies*

[22] SANS IEC 60034-16-3, *Rotating electrical machines – Part 16: Excitation systems for synchronous machines: Section 3: Dynamic performance*

[23] SANS IEC 60034-18-1, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 1: General guidelines*

[24] SANS IEC 60034-18-21, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 21: Test procedures for wire-wound windings – Thermal evaluation and classification*

[25] SANS IEC 60034-18-22, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 22: Test procedures for wire-wound windings – Classification of changes and insulation component substitutions*

[26] SANS IEC 60034-18-31, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 31: Test procedures for form-wound windings – Thermal evaluation and classification of insulation systems used in machines up to and including 50 MVA and 15 kV*

[27] SANS IEC 60034-18-32, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 32: Test procedures for form-wound windings – Electrical evaluation of insulation systems used in machines up to and including 50 MVA and 15 kV*

[28] SANS IEC 60034-18-33, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 33: Test procedures for form-wound windings – Multifactor functional evaluation – Endurance under combined thermal and electrical stresses of insulation systems used in machines up to and including 50 MVA and 15 kV*

[29] SANS IEC 60034-18-34, *Rotating electrical machines – Part 18-34: Functional evaluation of insulation systems – Functional evaluation of insulation systems – Test procedures for form-wound windings – Evaluation of thermomechanical endurance of insulation systems*

[30] SANS IEC 60034-19, *Rotating electrical machines – Part 19: Specific test methods for d.c. machines on conventional and rectifier-fed supplies*

[31] SANS IEC 60034-22, *Rotating electrical machines – Part 22: AC generators for reciprocating internal combustion (RIC) engine driven generating tests*

[32] SANS IEC 60034-23, *Rotating electrical machines – Part 23: Specification for the refurbishing of rotating electrical machines*

[33] SANS IEC 60034-25, *Rotating electrical machines Part 25: Guide for the design and performance of a.c motors specifically designed for converter supply.*

[34] SANS IEC 60034-26, *Rotating electrical machines Part 26: Effects of unbalanced voltages on the performance of three-phase cage induction motors.*

[35] SANS IEC 60034-27, *Rotating electrical machines Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines.*

[36] SANS IEC 60034-29, *Rotating electrical machines Part 29: Equivalent loading and superposition techniques - Indirect testing to determine temperature rise.*

[37] SANS IEC 60034-30, *Rotating electrical machines Part 30: Efficiency classes of single- speed, three-phase, cage-induction motors (IE-code).*

[38] SANS IEC 60050 (411), *International Electrotechnical Vocabulary (IEV) – Chapter 411: Rotating machines*

[39] SANS IEC 60072-1, *Dimensions and output ratings for rotating electrical machines – Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1 080*

[40] SANS IEC 60072-2, *Dimensions and output ratings for rotating electrical machines – Part 2: Frame numbers 355 to 1 000 and flange numbers 1 180 to 2 360*

[41] SANS IEC 60072-3, *Dimensions and output ratings for rotating electrical machines – Part 3: Small built-in motors – Flange numbers BF10 to BT50*

[42] SANS 10242-1:1999, *The rewinding and refurbishing of rotating electrical machines Part 1: Low-voltage three-phase induction motors*

[43] SANS 1561-1:2006, *Rewound and refurbished rotating electrical machines Part 1: Low-voltage three-phase induction motors*

[44] SANS 600317:16 *Specification for particular types of winding wires*

[45] SANS IEC 60851, *Winding wires - Test methods Part 1-6*

[46] SANS IEC 60085:1984, *Thermal evaluation and classification of electrical insulation.*

[47] SANS IEC 60270: 1981, *Partial discharge measurements*

[48] SANS 804:2008, 2.01 *Unwrought tough pitch coppers: Electrolytic tough pitch high conductivity copper*

[49] Eskom 240-50237155, *New MV Motor Procurement Standard*

[50] Eskom 240-54783039, *New MV Motor Technical Schedule A&B – Required Motor Specification & Tendered Motor Data Sheet.*

[51] Eskom 240-54783135, *New MV Motor Technical Schedule C – Manufactured Motor Data.*

[52] Eskom 240-54783158, *Standard Forms for Eskom Electric Motor Testing.*

[53] Eskom 240-56361435, *Transport of Power Station Electric Motors standard* (Eskom Specification)

[54] Eskom 240-56360387, *Storage of Power Station Electric Motors standard* (Eskom Specification)

2.2.2 Informative

[55] EPRI 1011892 Guideline for the Specification of Replacement and Spare AC Squirrel-Cage Induction Motors having Voltage Ratings of 2,300 V to 13,200 V; EPRI. Palo, Alto, CA.

2.3 DEFINITIONS

Unless otherwise indicated, the definitions of IEC 60050-411 shall apply, in addition to the following:

a. **Bearings:** A stationary member or assembly of stationary members in which a shaft is supported and may rotate.

b. **Repairer:** Motor Repair Service Provider

c. **Critical Motors:** Motors whose failure in service would have an appreciable probability of causing loss of availability of generating plants, or of causing unsafe conditions for personnel or plant.

d. **DC Step Voltage test**: The test is a controlled over-voltage test where designated voltage increments are applied at designated times and leakage current is recorded. The time increments can be constant or graded.

e. **Employer**: The Eskom business unit engaging in refurbishing or repairing electrical motors to which this document is applicable

f. **Medium Voltage**: Voltage ratings of 1000V and above

g. **Overhaul**: A basic refurbishment or a refurbishment with limited replacement of components (e.g., bearing replacements).

h. **Polarization Index (PI)**: Variation in the value of insulation resistance with time.

i. **Refurbishing:** The total process of restoring a machine or component that has become inadequate for continued use with normal maintenance, thereby making it suitable for an extended period of service. This may include re–evaluating the service conditions and use of the motor and possible redesigning of the motor to meet the new requirements.

j. **Repair**: Those steps required to rework or replace motor components to restore the motor to original design specifications.

k. **Rewind**: The process that includes the removal and replacement of the stator winding system in the motor.

l. **Rotor End Float**: This applies to horizontal motors with sleeve or tilting pad bearings. It is the total rotor axial movement of an uncoupled motor when the rotor is pushed from one extremity to the other and is limited by the distance between shaft journal shoulders and the width of the bearing.

2.3.1 Disclosure Classification

Controlled Disclosure: Controlled Disclosure to external parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Unless otherwise indicated, ISO abbreviations shall apply.

Abbreviation	Description
CACA	Cool Air Cool Air
CACW	Cool Air Cool Water
DAR	Dielectric Absorption Ratio
DE	Drive End
ETD	Embedded Temperature Detector
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IR	Insulation resistance
MV	Medium Voltage
NDE	Non-Drive End
NEC	New Engineering Contract
NEMA	National Electrical Manufactures Association
O&M	Operating and Maintenance
PI	Polarization Index
RTD	Resistance Temperature Detector
SANS	South African National Standards
SOW	Scope of Work
TVA	Tennessee Valley Authority

2.5 RELATED/SUPPORTING DOCUMENTS

[56] 240-50237155 New MV Motor Procurement Standard

3. QUALITY CONTROL AND ASSURANCE

The following are minimum requirements for Quality Control and Quality Assurance programs:

a. The *Repairer* shall have a QA program that, as a minimum, meets the requirements of ISO 9001 or *Employer* approved QA Program. Any sub-contractors completing any portions of the motor repair and reconditioning work shall meet this requirement. The *Employer* shall accept the QA program before the start of any motor refurbishment or repair work.

b. If new and/or replacement parts are procured, the *Employer* has the right to inspect these parts. Technical documentation shall be made available to the *Employer* for inspection. The documentation shall include but is not limited to the following, where applicable:

- New stator core steel test and dimensional data,
- Technical sheets of original and replacement stator coils, testing, and insulation system,
- Manufacturer's technical data for new stator lead cables,
- Details of original and replacement rotor bars and end rings,
- Details of original and replacement rotor shaft and spider arms,
- VPI Resin type and maintenance data,
- Burn-out and dry-out oven temperature charts,
- New bearing inspection and tests data, and
- Testing and Inspection reports.

c. The *Employer* has the right to impose witness and hold points, even after order has been placed. Witness and hold points can only be waived by the *Employer*'s Quality Assurance or designated representative in writing. The *Repairer* shall provide appropriate notice of an impending witness or hold point at least 48-hours prior to the event.

The following are examples of hold/inspection points to be witnessed:

- Incoming motor routine test, where applicable,
- Motor stripping where warrantee and insurance claims are involved,
- Pre-cleaning assessment,
- Refurbished motor routine tests, including the full voltage no-load test run,
- Pre and post coil stripping/burnout stator core loss tests,
- Inspection of stator core prior to coil insertion,
- Initial coil installation and testing (Surge Test and DC Hipot),
- Testing of completely rewound stator,
- Motor load test.

d. At any phase of the Works, the *Employer* or its authorized representative reserves the right to inspect motors and all their components. By entering into a contract with the *Employer*, the *Repairer* therefore, consents the *Employer* or its authorized representative to unlimited access to the *Repairer*'s, including Sub-*Contractor's*, premises at all reasonable times to the extent necessary to assess compliance with the provisions of this and such other documents as may apply to the refurbishment of motors. Such inspections shall not relieve the *Repairer* of its obligation or responsibilities under the contract.

4. REPAIR PROCESS REQUIREMENTS

A motor which is to be sent for repair/refurbishment will either be deemed to have failed or it shall have been scheduled for refurbishment by the *Employer*. There are two phases in the repair/refurbishment process of an electric motor. Initially Phase I, which is commonly referred to as the “collect, strip, and assess” phase, requires details necessary to develop the assessment scope of work in order to determine the repair scope of work. Once the repair scope of work is concluded, the repair process enters Phase II in which the motor is repaired and delivered back to site as per the final scope of work determined in Phase I.

This Work Instruction is structured to describe, in sequence, the processes to be undertaken within the two phases in order to reach the motor assessment and repair purpose. A flowchart illustrating the process of the two phases is seen in APPENDIX A.

4.1 PHASE I REQUIREMENTS

4.1.1 Motor failures and planned refurbishments

Once a motor has failed during service, or once a motor which is in a serviceable condition has been planned for refurbishment, the following activities shall be conducted in sequence:

4.1.1.1 Breakdown Report

The following requirements shall be performed by the *Employer* and are to be compiled to develop a Breakdown Report (APPENDIX D):

a. Initially a motor assessment shall be conducted while the motor is *in-situ* before its removal from the installation base. A visual inspection shall be conducted while the motor is *in-situ* before its removal where all abnormalities are recorded, together with photographs.

b. IR, PI and Stator Winding Resistance tests are to be performed where applicable, as per 4.4.2.2 Stator Winding Tests.

4.1.1.2 Assessment SOW

The *Employer* shall develop the scope of work for the collection, dismantling, and assessment of the motor by the *Repairer* Based on the investigations included in the Breakdown Report, the *Employer* shall compile an Assessment SOW. Requirements applicable to the Assessment SOW as per APPENDIX B.

4.1.2 Motor Collections and Shipment

Transport of motors is to be in accordance with document Eskom *240-56361435 - Transport of Power Station Electric Motors Standard*. The transport of motors which are still in a serviceable condition shall be transported by the *Repairer* with the necessary care to prevent damage as a result of the transport. The following are requirements:

a. The motor collection point and lifting requirements shall be managed by the *Employer*.

a. Only authorised *Employer* personnel shall load the motor to the *Repairer's* transport.

b. The *Employer* shall supply tools and resources necessary to clamp the motor shaft before transport leaves the collection point.

c. The *Employer* is responsible to inform the *Repairer* of specific Business Unit requirements, e.g. security requirements and collection times.

4.1.3 Motor Assessment

The successful *Repairer* shall implement the contracted Assessment SOW, without deviation, as specified in the following sub-sections:

4.1.3.1 Incoming Inspection

The *Repairer* shall, on receipt of the motor, perform the initial tests and checks listed in the Assessment SOW. The tests are to determine the probable cause of the failure if any, record the findings, and to determine additional work which may be required. The following is required:

a. A visual inspection shall be made to assess the general condition of the motor exterior for cracks, broken welds and missing parts. Photographs are to be taken sufficient to document the motor construction, including accessories.

b. If the motor was in a working condition all standard routine tests are to be performed on the motor, including the following (where applicable):

- Phase resistance test,
- Phase balancing and vibrations, during a test run.
- Tests shall be conducted as per 4.4.2.2 Stator Winding Tests.

c. If failed components are identified during the incoming inspection, the *Repairer* shall attempt to verify the cause and reflect the findings in a report.

d. Bearings or shafts shall be checked for any obvious problems by manual rotation of the rotor, if possible.

- The *Repairer* shall ensure that the bearings are adequately lubricated before performing the manual rotation check.
- If the motor is fitted with sleeve bearings, the manual rotation test may be omitted, but the bearings and journals shall be checked.

e. Bearing insulation measurement.

f. Measurement and record of the shaft extension run-out of the motor shaft.

4.1.3.2 Motor Dismantling

After completing the incoming inspection, the motor shall be dismantled to conduct the pre-cleaning assessment. Motors shall be dismantled as follows:

a. Motors that involve either warranty or insurance claims shall not be disassembled without the *Employer* giving a written ‘go ahead’ for the *Repairer* to commence with the disassembling. Arrangements shall be made for interested and affected parties to witness the dismantling. The *Employer* Assessment SOW shall have a HOLD-POINT for such a requirement. The *Repairer* is required to take pictures and records throughout the disassembly.

b. All motor components shall be marked with either the motor manufacturer’s serial number or *Repairer* s job number during disassembly. Any new stamp identifications added shall be applied to low stress areas with low stress punches. Old nameplates or stamp identifications of previous refurbishments on the motor are not to be removed. Bolts and small parts, from the motor shall be stored in dedicated containers marked with a *Repairer*’s job number.

c. End brackets and frames shall be clearly match-marked.

d. All components are to be properly stored thereby ensuring storage conditions do not adversely affect the components.

e. Records concerning the bearings are to be recorded in the Motor Assessment Sheet in Appendix B.

f. Rotor removal shall utilise one or two cranes to move the shaft, with a close fitting pipe installed over one end of the shaft to act as a shaft extension. Attention shall be paid to the following quality control requirements during this process:

- The location, make, type, size, clearances and orientation of bearings,
- Care shall be taken that the slings do not damage either the bearing surfaces or the rotor.
- Under no circumstances shall the stator windings be touched by any of the parts being moved.

g. Additional information gathered during disassembly inspections shall be used to support the cause of failure analysis. Failure causes shall be discussed with the *Employer* before repair work proceeds, unless this is waved in the contract.

4.1.3.3 Pre-cleaning Assessment

Prior to the motor being cleaned, all components shall be inspected and tested. Due to motor contamination however, some components may require cleaning for a complete inspection and testing. The *Repairer* shall notify the *Employer* of any anomalies identified and shall document findings with photographs.

4.1.3.3.1 Stator Assessment

The assessment of the stator shall include but is not limited to the minimum following requirements:

a. The motor lead insulation shall be inspected for cracks, frays, signs of brittleness, and swelling from oil contamination and other contaminants. Motor lead lugs shall be inspected for signs of overheating. A pull check for loose crimp connections shall be performed.

b. Inspect the stator insulation for signs of partial discharge (white powder-like deposits), cracking at blocking and bracing, dryness, brittleness or puffiness.

c. Stator slot wedges and end-winding bracing shall be inspected for looseness, missing and broken parts.

d. Inspect the stator core laminations for looseness, rubs, localized heating and vent duct blockages. Core clamping fingers and duct spacers shall be checked for looseness and missing parts.

e. Perform a rated core flux test as per 4.4.2.3 Core flux Test.

f. If the stator core has insulated through-bolts, the insulating washers at the ends shall be checked for cracks. The insulation resistance between the bolts and core should be measured and recorded.

g. Perform a visual inspection of the stator winding RTD’s or thermocouples if fitted.

h. Air baffles and mounting hardware shall be inspected for defects and missing parts.

If the motor has been subject to an insulation failure, the following stator assessment requirements are additional to the above inspection points, and shall be met before the winding is cleaned:

i. The *Employer* is to be notified of the date and time when the failed coil removal shall take place.

j. Oven burn-out of the winding before the ‘cold’ removal/stripping, of the failed coil/s, is not allowed.

k. The failed coil/s shall be identified and isolated from the other winding coils. The point of flashover shall also be clearly identified. The identification shall be in the form of a winding drawing showing the location, both physically and electrically, in the winding circuit.

l. The failed coil/s and damaged winding sections shall be electrically isolated from the ‘healthy’ winding sections.

m. The non-defective remaining coils shall have the insulation system tested using DC and AC electrical test methods, which shall include the IR and PI tests, and AC or DC Hipot tests. The *Employer* shall decide on the level of Hi-Pot test to be conducted on the remaining winding. The minimum testing levels are contained in the appropriate test sections of this document.

n. The damaged coil/s shall be carefully removed to avoid damage to adjacent healthy winding and insulation.

o. The *Employer* reserves the right to request the *Repairer*’s permission to remove the failed coil/s, and any other coil that the *Employer* may deem necessary for failure analysis, from the *Repairer*’s workshop. The *Repairer* shall not deny the *Employer*’s request for coil/s, or part thereof, to be removed from the *Repairer* s Workshop.

p. Dissection of the failed stator coil is essential. Dissection of adjacent coils which have not failed is also essential, although sometimes the area immediate to the failure has been completely burned away by the fault. The *Employer* shall conduct the analysis, with the assistance of the *Repairer*’s suitably qualified personnel, if so requested.

q. The *Repairer* shall produce a diagram of the original stator winding with connections prior to the removal of the winding from the stator. This diagram shall include the locations of all winding RTD’s, or thermocouples. The location of the phase groups shall be referenced to a fixed point on the stator core. Winding and temperature detector terminal identifications shall be recorded on this diagram.

4.1.3.3.2 Rotor Assessment

The rotor assessment shall include the following checks:

a. The rotor core shall be inspected for looseness, overheating, loose, cracked, or missing clamping fingers and vent duct spacers, rubs, localized heating and blocked vent ducts. If overheating is found, inspection for signs of cracked rotor laminations or core migration is required. If defects are found, the *Employer* shall be contacted prior to any cleaning in order for an own inspection and discussion of repair strategy to take place.

b. The motor fans shall be visually inspected for cracked or loose blades, and on welds and hubs using the dye penetrant and ultraviolet light method. Looseness between the fan and its hub shall be checked.

c. Inspect, with magnification, the rotor bars and end rings for cracks, looseness, signs of localized heating and cage migration. If cracks are suspected, a dye penetrant and ultraviolet light method test is to be performed. Alternatively one or more of the tests described in the sub section 4.4.2.4.3 Rotor bar test is to be performed to check for breaks in the rotor cage winding.

d. Visually inspect the rotor shaft and spider for cracks using the dye penetrant and ultraviolet light method.

e. Check the straightness of shaft extensions, bearing journals, and rotor body by conducting total run-out measurements as contained in the mechanical checks section.

4.1.3.3.3 Bearing Assembly Assessment

The assessment of bearing assemblies shall include the following

a. Inspection and measurement of sleeve bearing journal housings and rolling-element bearing housings for correct fits to their respective bearings, in accordance with design values from either the motor OEM drawings or the bearing manufacturer's catalogue. From these measurements comparison is required for the bearing housing fit to the design values.

   - Recording bearing fit dimensions.

   - Performing a visual check of the bearing housing bore for evidence of fretting that may indicate a loose fit between the bearing and its housing.

b. A check of the bearing white metal surfaces for evidence of wipes and wear. Measurement of the sleeve bearing bores is required at three locations and records of measurements to be in an Assessment Sheet. If the white metal wear pattern indicates misalignment or other problems, the details of this shall be recorded.

c. Determine the bore roundness of sleeve bearings as per subsection 4.4.4.1 Mechanical checks during assembly.

d. Inspect oil rings and oil seals for signs of excessive wear and any other defects. Check oil rings for roundness, roughness of edges, and, if applicable, tightness of split oil-ring screws. Roundness shall be within 0.127mm. Check the oil-ring viewing port glass in the bearing housing for transparency.

e. The nominal seal-to-shaft clearances are to be documented by measuring the seal bores and using measured shaft diameters.

f. Check for evidence of rubs and leaks on the water coolant spiral of motors with water cooled oil reservoir bearings. Coolers shall be inspected for evidence of erosion and corrosion, and shall be pressure tested. The pressure test shall be conducted for 30-minutes as follows:

   - Either a water pressure test at 125% of the cooler water supply system pressure, or the cooler manufacturer's test pressure. Under no circumstances should the cooler manufacturer's test pressure be exceeded.

   - For an air, or other gas, e.g. nitrogen or helium, pressure test: the cooler at not greater than 500 kPa.

g. Check bearing brackets for cracks or any other defects.

h. Check the bearing insulation on the outside of the sleeve bearings for damage, wear, and overall dimensions.

4.1.3.3.4 Assessment of motor Accessories

The motor accessories shall be checked as follows:

a. Space heaters and the heater wiring shall be functionally and visually checked. If significant corrosion is identified inside the motor, the root cause is to be investigated.

b. Bearing temperature detectors shall be functionally and visually checked.

c. All other accessories shall be functionally checked.

4.1.3.4 Cleaning

a. The cleaning and drying method should not adversely affect the insulation ageing and integrity.

b. Stator and Rotor that are found to be clean and uncontaminated shall not be washed, unless agreed with the *Employer* as part of the scope of work.

c. If the windings (stator and rotor) are contaminated with any form of dust which has not hardened on the winding components, cleaning shall be by compressed air or blower only. The pressure at which air shall be blown through the windings shall be adequate for dust removal without damaging the insulation exterior.

If the winding/s (stator and rotor) are contaminated with any form of dust and/or oil/grease/water, the windings shall be cleaned as follows:

d. Stator windings with hardened contaminants and blocked air vents shall be soaked with an appropriate detergent prior to pressure cleaning. Cleaning by means of solvents may only be utilized where it is suitable for the application. Prior to the application of solvents approval is to be obtained from the *Employer*.

e. The machine is to be cleaned by a method such as low pressure steam with a maximum pressure of 206 kPa (30psi).

f. In the absence of a low pressure steam, a power washer with a maximum nozzle pressure of 1379 kPa (200psi) shall be used.

g. During the cleaning process, care is to be taken to ensure that foreign particles are not lodged into the insulation (cracks and crevices) where it can remain trapped.

h. Where cleaning methods such as dry-ice cleaning is recommended or utilized, a method statement is to be provided to the *Employer* for review. The method statement is to include preventative measures to mitigate the risk of insulation damage.

i. Any detergent, or other cleaning agent used shall be completely flushed from the stator after cleaning.

Cleaning shall be considered complete if all the air-vents have been unblocked and all contaminants intended to be cleaned-off the component surfaces have been removed. The *Repairer* shall conduct the assessment prior to dry-out and inform the *Employer* if the initial cleaning process was unsuccessful.

The *Repairer* shall recommend options for a successful cleaning, including the following:

j. A second cleaning process, which will be a repeat of the initial cleaning procedure.

k. An alternative cleaning method that is suitable for the removal of remaining grime.

4.1.3.5 Motor Dry-out

4.1.3.5.1 Oven Capabilities

A completely cleaned stator shall be dried out in an oven which has the following minimum capabilities:

a. Time stamped trend recording of the oven dry-out, to be trended throughout the drying process. The time-stamped record of the dry-out process shall be kept and provided to the *Employer* for record keeping. The oven temperature is to be recorded electronically and not manually and is to be representative of the highest temperature in the oven.

b. Drying of the windings is to be done in an oven with the oven temperature controlled within the range of 100°C - 110°C.

c. Automatic temperature control to the range specified above. For feedback, the control system shall use air temperature sensors at different locations in the oven. Motor winding temperatures shall preferably also be monitored.

d. Hot air circulation by an electric fan or blower.

4.1.3.5.2 Dry-out process

The dry-out process shall be as follows:

a. In order to avoid steam damage, for the first 6 hours the oven temperature shall not exceed the boiling point for water based in the oven environment, i.e. 94°C in Johannesburg.

b. After 6-hours, the oven temperature may be raised but shall not exceed the thermal rating of the stator winding insulation system, including the leads, less 10°C, for the remaining duration of the dry out. As an example for Class F insulated machines, the oven temperature shall be set, monitored, recorded and controlled not to exceed 105°C.

c. The motor winding temperatures may also be monitored, recorded, and fed back to the oven control system and not to exceed 90°C.

After dry out, the IR and PI tests shall be performed to confirm the winding is dry as per subsection 4.4.2.2 Stator Winding Tests. The conditions for the test and acceptance of the motor as being dried out are:

d. The winding shall be within 10°C of ambient temperature before final IR acceptance testing is performed.

e. The dry-out should be considered complete if the previously benchmarked dry IR, as indicated by PI and IR1min, is reached. A compromise consideration may be to deem the dry-out as successful when IR1min and PI measurements show levels higher than the minimum acceptance values in Table 2: Insulation Resistance Test Acceptance Criteria.

4.1.3.6 Post-cleaning Assessment

If any motor component has not been completely inspected and tested as specified during the pre-cleaning assessment, such a component shall have its specified inspection and testing completed after its cleaning and dry-out.

When specified in the Assessment SOW, the concentricity of the bearing mounting flanges on the stator frame and bearing housing bores, relative to the stator bore shall be checked and recorded by the *Repairer* on the motor Assessment Sheet.

4.1.3.7 Failure Report

When a motor is received in a failed condition, all effort must be made to determine the root cause of failure. In the case of uncertainty, all possible root causes are to be listed. Root causes of the failures are to be determined during the various stages of the refurbishment process such as testing, dismantling, etc. Abnormalities that could have contributed to the failure are to be properly recorded.

The *Repairer* shall submit a report detailing findings together with photographs identifying the symptoms identified. Recommendation of corrective and preventative actions is to be provided. This report shall be summarised in the Assessment Sheet, typical example seen in APPENDIX B, with the detailed report e-mailed to the *Employer* as a separate document.

4.1.3.8 Repair SOW

4.1.3.8.1 Requirements

The *Repairer shall* provide the *Employer* with a recommended repair SOW based on his own analysis of the failure and the need to fulfil the repaired motor performance requirements. The recommended SOW is governed by the following requirements:

a. It shall be based on the Inspection Outcomes Action column of the MV Motor Assessment Sheet in Annex B. Deviation from the *Employer*'s inspection outcomes actions is allowed, provided that the *Repairer* technically justifies the deviation.

b. It shall be e-mailed to the *Employer* for review and influence.

4.1.3.8.2 Employer's SOW

The *Employer* shall review the recommended SOW and, considering all documentation provided by the *Repairer* and the Inspection Outcomes Action column of MV Motor Assessment Sheet in Annex B, shall prepare the repair SOW that shall be the discussion document at the repair site meeting. The *Employer*'s SOW shall include:

a. Nameplate and failure assessment details about the motor.

b. Relevant QC&A details on tasks, where necessary.

c. It shall include the requirement for the date by which the motor is to be delivered.

4.1.3.8.3 Repair & Reconditioning Tasks

As a guideline, the following repair and reconditioning tasks shall be included in the SOW:

a. All broken or rusty miscellaneous hardware such as nuts, bolts, and washers shall be replaced. New hardware shall be of a similar or better grade to that being replaced.

b. Repair loose wedging and replace any loose end winding bracing components.

c. Repair any stator core defects

d. Replace any cracked or broken core bolt insulation.

e. Missing, or defective baffle mounting hardware shall be replaced and mounting bolts shall, or shall be locked in place by applying a threadlocker to bolt threads or by other equivalent means to prevent loosening in operation. Air baffle damage shall be repaired.

f. Rotor core defects shall be repaired as per the discussed repair strategy.

g. Any rotor fan and/or rotor bar defects shall be repaired

h. Cracks in welds are to be repaired

i. All rolling-element bearings shall be replaced. Repair bearing housing defects and restore bearing fits in accordance with subsection 4.2.1.4 Bearing Assemblies.

j. Defective oil rings shall be repaired, or replaced. Screws in split oil rings shall be tightened and locked in place by pining or some other means. If the oil ring viewing port glass in the bearing housing is no longer transparent, it shall be replaced.

k. Defective bearing insulation shall be replaced

l. Defective heater wiring and resistive elements shall be replaced. After such replacement a check shall be carried out to ensure no heater wiring is too close, or touching a heater element. Additional space heaters should be installed if excessive corrosion is found to have resulted from the inadequate capacity of the existing heaters.

m. Coating the insulation system with multiple layers of ‘insulating’ varnish may be detrimental to the cooling efficiency of the motor. If the stator insulation is found to be in satisfactory condition, an assessment shall be conducted by the *Employer* to determine if the rotor and stator shall be coated with any form of painting.

4.1.3.9 Repair vs Replacement

The *Employer* shall technically and economically evaluate the replacement of failed motors, when one or more of the following conditions are valid:

4.1.3.9.1 Economic Evaluation

a. The motor requires the replacement of major components such as; the stator windings, rotor cage, stator core, and rotor core.

b. The failure analysis identifies the failure to be due to either a patent or latent design fault.

c. The failure analysis and failure rate of similar motors show that the motors are failing due to ageing, or design unsuitability to application.

4.1.3.9.2 Cost/Benefit Analysis Ratio

The evaluation is to be based on the ratio of cost/benefit analysis using credible and justifiable assumptions. As a basic ‘rule of thumb’, the recommendation may be based on the costs of the proposed repair work versus the costs accumulated for a new motor. A rule of thumb analysis ratio would be as follows:

a. If the repair costs are less than 50% of the accumulated costs of a new motor, then the motor should be repaired.

b. If the repair costs are in-between 50% and 70%, the *Employer* needs to assess the motor condition based upon the budget and requirement to return the motor to service.

c. If the cost of repairs is greater than 70% of the accumulated costs, there should be a strong recommendation made to procure a new motor and, if necessary, devise a contingency plan for the Station to cater for the lead times of the new motor.

d. If the motor repair history indicates poor reliability of the design, the *Employer* shall conduct an investigation to modify to improve reliability or replace the motor with a suitable design.

e. If the motor has to be replaced, it shall be scrapped as per applicable electric motor scrapping procedures and the replacement motor procured as per Eskom 240-50237155. The *Employer* may decide to have the motor, which is to be replaced, reconditioned as a spare while the delivery of the replacement is awaited. All relevant warranties/guarantees are to be considered to determine *Repairer* liabilities.

4.2 PHASE II REQUIREMENTS

The motor repair/refurbishment strategy to be utilised shall be determined by the relevant Business Unit and shall be agreed upon by the relevant technical personnel, the end users and the respective commercial departments.

4.2.1 Motor Repairs

4.2.1.1 Stator Windings

4.2.1.1.1 Complete Stator Windings

If a complete stator rewind is necessary, the following methods and procedures shall be used:

a. All materials employed in the stator winding system shall be compatible and suitable for continuous operation at a Class F (155°C) hot spot temperature or higher. The combined system of insulating materials shall have been certified as suitable for Class F or higher.

b. Winding insulation shall be oil resistant & non hygroscopic.

c. Conductors shall be of high conductivity copper to SANS 804 of rectangular section having dimensions, tolerances and corners radiuses according to SANS 600317.

d. Conductor insulation is to comply to modern systems of rewinding appropriate with IEC standards. Breakdown, bending and elongation tests on the covered conductor shall conform to the relevant IEC standards.

e. If stator windings have to be burned out, it is recommended that the stator end-windings are cut-off prior to insulation burn out to facilitate better oven temperature control. The process shall be done in an oven with the following capabilities:

- Automatic precision temperature control system that shall use air temperature sensors at different locations in the oven and winding or core temperatures as control system feedback. The core temperature shall be controlled not to exceed 300°C with a tolerance of ±3.5%.
- Time stamped trended recording of the oven burn-out process. The time-stamped record of the burn-out process shall be kept and provided to the *Employer* for record keeping.
- A water spray quenching system.

f. If burn out temperatures higher than the specified limits are used and the stator core losses after removing the old winding are 5% greater than the initial pre-stripping core loss, the *Employer* shall be contacted. All expenses for restoring the core losses to less than the 5% limit because of core loss degradation occurring during winding removal shall be the responsibility of the *Repairer.*

g. All core repairs and testing is to be completed before installing the new winding.

h. If the winding has to be replaced with the same insulation system winding, the new coils shall have the same number of turns, same number of conductors, same turn and strand insulation, and same conductor cross-section area as the original coils. The thermal rating and thickness of the ground wall insulation shall be the same, or greater than that of the original winding. All proposed changes from the original winding system shall be discussed with the *Employer* prior to implementation.

i. Where replacement coils and bars have a loose fit due to modern insulation types, it is preferred that copper sizes be appropriately increased first to improve the fit. Conductor size may be modified only with the approval of the *Employer* having evaluated the modification impact on motor performance parameters, which will have been provided by the Repairer's suitably qualified and appropriately registered Engineer to conduct motor designs.

j. In general, loose fits between windings in core slots should not be remedied by means of increased insulation. Insulation thickness (conductor and strand) should also not be less than the original design unless improved insulation materials are utilised.

k. The guidelines for the Vacuum Pressure Impregnation (VPI) process is as follows:

- The rewind insulation system for complete form wound windings, to be utilised, is the global VPI process.
- Where the global VPI process is not possible, the *Employer* is required to approve the alternative process, prior to the rewind process starting.
- Within the global VPI process, preference is to utilise the rotate curing process. This process is to ensure the least amount of separation of resin and insulation during curing. If the resin is viscous enough not to run during curing, the rotating process may be neglected and proof is to be provided.
- Data logging is to be carried out throughout the entire VPI process. This includes the initial heating cycle and eventual oven curing. In this way the entire process is reviewed.
- A data logging print out generated from an automatic data logging system is to be supplied for review subsequent to the VPI process and prior to final testing. The data logging print out is required to form part of the final report.
- Only printed logging sheets generated from an automatic data logging system are acceptable. No handwritten or artificially generated log sheets will be accepted.
- As part of the VPI process, the capacitance of the motor is to be measured during the impregnation cycle. This capacitance measurement should be part of the data logging print out.

From the print out, it is to be clear that the capacitance has stabilised (resin impregnation is complete).

- The VPI process is to ensure the VPI resin is properly degassed prior to the resin filling of the motor tank.
- The VPI process is to ensure that the ventilation/cooling slots, ducts and pipes are not blocked by the resin. Where possible the slots, ducts and pipes are to be inspected for blockages prior to the VPI process and prior to baking. This necessitates sufficient dripping time between the VPI tank and the oven. The motor is to be rotated and re-aligned to ensure maximum resin drainage during the dripping time. The motor is to be positioned in the oven such that maximum drainage is ensured.

l. Acceptable materials for use as strand insulation are; double Dacron glass, Nomex 418, and mica tape wrapped or fused over bare copper or Class 180°C and higher enamel, or equivalent.

m. Based on the required volts/turn capability of conductor insulation, an appropriate number of ½ lapped layers of mica tape shall be used as turn insulation over strands insulated with acceptable materials. Motors rated above 6kV shall have a minimum of two ½ lapped layers of mica tape. Turn insulation shall be reinforced at the coil knuckles and the conductor stacks shall be fully consolidated in the straight sections of the coil legs before application of the ground-wall insulation. Kapton polyamide film is not acceptable as turn insulation material.

n. Ground-wall insulation requirements include the following:

- The new coils must have at least the same number of ½ lap mica tape layers of insulation as the originally taped coils. Mica tape shall be supported by glass cloth, polyester mat, or floc compatible with the VPI epoxy, or polyester resin to ensure proper resin penetration and bonding.
- Tapes containing polyester (Mylar™), Polyamide (Kapton™), or other films are not acceptable.
- The ground-wall insulation on the end windings and connections shall have the same number of layers of insulation as the slot portions. If the *Repairer* is concerned that winding cooling and inter-phase spacing may be compromised, a concession on this issue should be agreed upon between the *Repairer* and the *Employer*
- All windings shall have corona suppression applied. Corona suppression tapes may slow the flow of resin into the insulation system during VPI processing and, therefore, require a longer treatment time than normal. All motors shall, therefore, be put through the VPI process that is not shorter than that normal for 11kV windings.
    - Corona suppression for 11kV windings shall consist of carbon, or graphite semi-conductive tapes applied to the slot sections that shall extend at least 25 mm beyond the end of the core. Silicon carbide grading tape is to be used on the end windings, and this shall overlap the semi-conducting slot section tape and extend to approximately 50 mm past the first bend of each coil.
    - 3.3 kV motors shall have semi-conductive tape applied to their slot section.
- The maximum clearance between the coils and core slots shall be 0.25mm/side.

o. The stator winding shall have two embedded temperature detectors (ETDs) or RTDs, type PT100 that are either 3-wire or 4-wire, located in the hottest part of each phase winding. Where the hottest part of the winding is not in the middle of the core section, additional PT100 RTDs shall be embedded in the middle of the slot between coils of each phase. The ETDs shall have shielded leads and all shall be connected to a terminal strip in the ETD terminal box.

p. Materials acceptable for use in end-winding lacing and tying are; heat shrinkable tape, rope, cord, or tie materials made of glass roving. Tapes of 100% Dacron are not allowed.

q. Acceptable end-winding blocking materials are; epoxy or polyester-saturated Dacron® or Nomex ® felt materials or glass mat.

r. The under-wedge packers (filler strips) shall be rigid glass epoxy laminates to enable the replacement of wedges without possible damage to the global VPI stator winding insulation. Rigid polyester fibreglass and a felted Nomex ® may also be used as the under-wedge filler to achieve the coil protection and the objective of a secure fit. Use of exclusively soft under-wedge packing material is unacceptable.

s. Mid slot and bottom packers as well as side packers, if necessary, shall extend at least 13 mm beyond each end of the stator core.

t. With semi-conductive tape applied to all coil straight portions, filler strips and side packing made of semi-conductive material which has conductivity limits of 1,000 to 10,000 ohms/square shall be used.

u. Wedges shall be replaced as follows:

- Wedges shall as far as practicable be replaced with wedges of the same type as the original windings. The wedge material utilised should not substantially change the efficiency of the motor. If the original type is unknown, the preferred wedges are *epoxy* type wedges. Should magnetic wedges be offered, the *Employer* is to be provided with written proof that the wedges will provide the expected life. Epoxy Glass laminate type are not acceptable. Replacement wedges shall be bonded with an epoxy resin to the slot, but without causing air-vent blockages
- The *Employer* is to approve the *Repairer* wedge removal/ replacement procedure prior to the replacement process. Where removal of wedges might pose a risk of damage to the winding insulation, the *Employer* is to be notified beforehand. Removal of wedges only to be carried out following approval by the *Employer*.
- If more than 10% of the motor wedges are found to be loose, all motor wedges shall be replaced. This is provided the ground wall insulation is not damaged in the process.
- Special attention shall be given to the accurate tight fitting and wedging of the stator bars. This is to reduce partial discharge and to prevent the bars from vibrating in the slots. Thereby preventing erosion of the corona shield.
- In order to ensure that wedges have not become dislodged or loose in service, wedges are required to be tight fit and epoxied in place by means of the appropriate epoxy.
- During the wedge removal/replacement process emphasis is to be placed on:
    - Ensuring that no foreign material is trapped between the wedge and the winding insulation/space/core.
    - Ensuring no damage is done to the core, which may lead to shorted laminations.

v. All connections between coils, phase rings, and leads are subject to the following:

- Connection are to be brazed with a material containing at least 15% silver and completely sealed with full ground-wall insulation of mica tape, and a final layer of glass or Dacron® armour tape.
- Jumpers shall be constructed from copper conductors that have at least the same cross section as those in the coils and shall be insulated with full ground insulation. Dacron® or Nomex ® felt

spacers shall be used, where needed, to make the connection structure more rigid and provide phase separation. Where possible, additional series connection bracing shall be furnished by tying series connections to a resin impregnated rope.

- All shall be insulated with the same number of layers of mica tape as the coils.
- The use of motor lead cables for connections, jumpers, etc., around any part of the end windings, is not acceptable.

w. After connections between coils have been completed, but before the new winding is put through the VPI process, the winding rotation and quality of brazing shall be checked and tested using the power (induction) test. This test, which shall be witnessed by the *Employer,* and shall have two parts:

- The first part shall be to verify correct connection of the winding by supplying adequate power to the winding and using a ball bearing or dummy rotor to ensure that there is proper rotation. The rotor or dummy bearing shall not stop or reverse direction if the connections are correct.
- The second part shall be to check the brazing joint quality by increasing the voltage supply until the line currents are equal to rated full load current. As the winding warms up, thermal evaluation of the end-windings shall be conducted using an infrared camera. Comparison between coil turns and brazed connections shall be made. Acceptance criterion is that the thermal images of brazed connections shall not exhibit higher temperatures than the coil end-turns.

x. Only polyester and epoxy resins are acceptable.

y. The *Repairer* shall have a QA&C method of ensuring adequate resin penetration into the conductor before the stator can be removed from the VPI tank for curing.

z. The VPI process including time, temperature, and vacuum and pressure values shall conform or exceed the resin *Vendor*'s recommendations. Time stamped recording of the VPI process shall be kept for each job and provided to the *Employer*, when requested.

aa. Each motor rewind shall have at least one sample coil put through the VPI process. Requirements for sample coils are:

- The sample coils shall be manufactured as the motor coils, including the specified corona protection. Both coil slot sections shall be embedded in steel or aluminium channels that simulate the specific motor’s stator core portions. If the core does not have air-vents, the slot portion may be wrapped in earthed conducting tape or foil, but steel or aluminium channels are preferred.
- At least 1 (one) spare coil shall be fully processed with the motor in the entire VPI and Curing process.
- After oven curing, but before any winding testing, the completely processed sample coil shall be subjected to insulation tests. Such tests shall include but is not limited to IR, Tan-δ, and Impulse Voltage tests.
- The *Employer* reserves the right to keep the whole sample coil or portions thereof.

bb. Motor lead cables shall be installed after impregnation to prevent ingress of resin during the VPI process. Requirements for tail leads are:

- They shall be rated to carry at least 125% of motor full load current and have an insulating covering that has a thermal rating of 155°C rating or higher.
- The preferred cable insulating material is silicone rubber with an outer glass over-braid for mechanical protection. Other types of cable insulation may be used if approved by the *Employer*

and are to be sleeved with a silicone coated glass braid to protect them from the effects of lubricating oil.

- The length shall be at least 1 (one) meter and a slack of at least 500 mm.
- The motor leads shall be permanently marked identifying the relevant phase of each. Metal band tagging is not allowed.
- Lead spacing and clamping devices shall be used between the winding and terminal box and where the lead cables pass through the stator frame to the terminal box. In this manner the lead cables are to be adequately secured.
- The motor lead lug size shall be equivalent to the original size.

4.2.1.2 Stator Core

a. A stator core loss test shall be performed at the following stages of repair:

- Before any stator core, or winding repairs are performed
- After removal of the stator winding for replacement.
- After stator core, or winding repairs

b. Where the core testing and inspection indicates a degraded core, this needs to be indicated to the *Employer* including a recommended repair procedure.

c. If core inspection and/or testing indicate shorts between laminations, these shall be cleared to obtain a satisfactory core loss test and to eliminate hot spots. The *Employer* is to authorize any core repair technique.

- Where hot spots need to be removed by means of grinding/machining, written approval needs to be obtained from the *Employer*. Re-insulation of the core with materials that have a thermal rating of 540°C or higher may be required after core skimming. A successful core skimming process results in no hot spots outside of acceptable limits.
- Restacking or replacement of the core shall be a solution for deep lamination insulation damage when a stator has to be rewound.

d. The *Employer* is to be supplied with a written repair method. The expected impact which the proposed repair method has on the motor efficiency/performance is to be highlighted in the report.

e. Where it is recommended that the core is to be reused, a repair method is to be provided that will include the insulating of laminations such that hot spots are mitigated and prevented as far as possible.

f. If the core restack is necessary, this shall be done as follows:

- Prior to the restacking of the core, approval needs to be obtained from the *Employer*.
- The *Repairer* must make a gauge bar that can be appropriately inserted through each original slot.
- Unstack the core, flatten, and de-burr laminations as required.
- Remove all loose and flaking varnish.

- Coat at least one side of each lamination with a uniform layer of acceptable insulation material. Excessive insulating material build-up and runs must be avoided.
- Dry coated laminations in an oven for coating to cure and provide the best possible uniformity for stacking.
- To ensure uniformity, parallelism, and correct sizing of the slots, careful control of the stacking process is mandatory. Such control includes the following actions and requirements:
    - During the stacking process, press the core stack at a minimum of one third of the core length and check the slot dimensions to be within the original dimensions.
    - The gauge bar must be inserted to check the slot dimensions.
    - Grinding of the slots or dovetails to correct the slot dimensions is not allowed. If the gauge bar cannot be inserted, the core restack shall be re-started.
    - The final core length must be equal to the original core length. The only allowed tolerance is 0% to -0.5%.
    - The restacked core must be located within the frame to prevent rotor magnetic centre shift.
    - It should not be possible to insert a 0.5mm filler gauge between any laminations.
    - No area of the core may build up heat outside the acceptance criteria after restacking is complete.

g. Core replacement is subject to the following requirements:

- Core replacement material is required to match the original component dimensions of the motor. Material specifications are to be the same or an improvement of the original specifications.
- The *Repairer* shall provide the thickness, Magnetization losses (W/kg) at 50 Hz, and exciting currents for both original and new laminations.
- Replacement core laminations shall be of the same size and shape as the originals, but may be made of higher grade of steel.
- New laminations must be burr free.
- Magnetization losses (W/kg) at 50 Hz and exciting current of replacement laminations shall not exceed values of the original laminations.
- "Short-stacking" or providing less than original core length is not permitted.
- Cooling air vents shall be restored to original dimensions and locations.

h. Loose core clamping-fingers or duct-spacers should be tightened, or replaced.

i. Damaged core through-bolt insulation shall be replaced.

j. The repair method is to include particulars of all replacement materials. Deviations from original specifications are to be clearly indicated to the *Employer*. The following information is to be included in the documented repair method:

- Thickness
- Watt per kilogram loss at 50 Hz
- RMS exciting current

4.2.1.3 Rotor

4.2.1.3.1 Rotor cage repair

All repairs on the rotor cages shall be conducted as follows:

a. If the assessment shows any cracked or broken bar, or broken shorting rings, or complete cage migration in one direction, the cage shall be replaced with material of the same size, grade and conductivity. Metallurgical and conductivity tests shall be performed on original and new bar and ring materials to confirm compatibility with the original rotor specifications.

b. Broken bar-to-shorting ring or shorting ring joints may be repaired. Rolled shorting rings with broken joints shall be replaced by a single-piece forged or cast rings. The complete shorting ring shall be removed and all matting surfaces on bars and single-piece forged rings cleaned before re-brazing the joints.

c. If loose bars are found, but are not broken or cracked, the *Repairer* shall recommend a method of tightening the bars for acceptance by the *Employer*. Dipping and baking the rotor in epoxy, polyester, or any other type of resin or varnish is not an acceptable repair method for loose bars.

d. If die-cast aluminium rotor windings are found to have deep cracks, or breaks, the complete winding, or rotor shall be replaced. Replacement of die-cast rotor cage windings with fabricated types is not acceptable.

e. If the core damage is not too extensive, skimming the rotor in a lathe with a sharp tool should eliminate surface smearing. Such repairs shall not increase the stator-to-rotor air gap by more than 10% and should only be performed once in the life of the rotor core. Acid etching or high speed grinding may be used to repair localized damage.

f. Rotor winding joint repairs shall be checked for defects using one of the specified test techniques as per the section Inspection and Testing.

g. Rotor core laminations damaged due to broken rotor bars, looseness, or any other cause, shall be considered for replacement if extensive.

h. Loose and missing duct spacers and end fingers shall be fixed in-place by spot welding.

4.2.1.3.2 Journals, mounting surfaces and shaft extensions

Repairs on friction type bearing journals, ball and roller bearing mounting surfaces, seal surfaces and shaft extensions shall be conducted as follows:

a. Superficial damage can be polished up with a microfiber cloth.

b. More severe damage requires the correct shaft diameter and surface finish to be restored as follows:

- Remove the damage by machining followed by rebuilding with micro-welding,
- Grind the surface to restore shaft diameter to correct dimensions and surface finish as follows:
    - Bearing journals – 410 μmm, or better
    - Rolling element bearing mounting surfaces – 810 μmm, or better
    - Thrust runner, or bearing hub mounting surfaces – 810 μmm, or better
    - Shaft extensions – 810 μmm, or better

- Bearing seal surfaces – 1625 µmm, or better
- Metal spraying is not allowed

4.2.1.3.3 Shaft Replacements

Bent shafts that cannot be straightened or broken shafts shall be replaced as follows:

a. Record all critical shaft dimensions relative to one shoulder prior to the start of shaft removal.

b. Tighten the core, if necessary, before the shaft is removed.

c. Remove all shafts, except for 2-pole motors with fabricated rotors, by pressing them out of the cage.

d. The *Repairer* shall obtain OEM information on the existing shaft material if the *Employer* cannot provide such information. If the shaft design information is not available, tests shall be conducted on the old shaft to determine its material properties, including hardness.

e. Select and confirm the new shaft material to have properties that are similar to that of the old shaft.

f. Machine all shaft steps, including keyways, to incorporate appropriate radii to avoid stress concentrations.

g. Shrink fit the shaft into the core.

h. Check and ensure concentricity of the shaft with the core outside diameter.

i. Perform final shaft machining.

j. Spider arm weld cracks that have been verified by dye penetrant tests require grinding and welding repair if grinding cannot eliminate surface cracks.

k. Cracked cooling air fans shall be replaced and loose components, such as those used for balancing, shall be welded. If the fan is hub mounted and the mounting is found to be loose, the shaft OD, or hub bore shall be built up to restore an interference fit of 0.125 mm. per mm of shaft diameter. Any damaged keys, or keyways used to connect a fan hub to the rotor shaft shall be repaired.

l. Rotor balance check as per the section Inspection and Tests shall be performed on all motors being reconditioned or repaired after rotor cleaning and after any rotor repairs.

4.2.1.4 Bearing Assemblies

4.2.1.4.1 Anti-friction Bearings

Anti-friction bearings are not be repaired and shall be replaced during motor reconditioning and/or repairs that involve disassembly. Anti-friction bearings are to be inspected for abnormalities and the *Employer* is to be provided with a report of the findings. The following procedures shall be followed when installing new rolling element bearings:

a. The bearings shall have metal cages complying with ISO/15:1998 with radial clearance of C3 (3dot).

b. During bearing installation, heating shall be within the tolerances laid down in the relevant bearing manual and shall not exceed 110ºC. This takes place using an induction heater with a demagnetizing facility. This is also relevant where bearings are removed with the intention of putting it back in service. The use of used bearings is not permitted unless it has been so instructed by the *Employer*.

c. Bearing housings shall be checked dimensionally and for concentricity to ensure the required tolerances are met as specified in the bearing selection and maintenance manuals.

d. Tolerances are as follows:

- Ball Bearings - J6
- Roller Bearings - K6

e. The new grease-lubricated bearing should be packed with the type and grade of grease specified in the motor nameplate data or as specified by the *Employer*.

f. During installation the bearing must be pushed on to the shaft or mounting hub by its inner race.

g. Unless the motor manufacturer or experience indicates otherwise, the bearing housings shall be 2/3 packed with new grease of the type specified.

h. Bearing housings with oversized bores shall be bored out, sleeved and machined to restore the correct bearing outer ring-to-housing fit. The bearing housing wall thickness shall not be reduced by more than 25% during such repairs.

i. Out-of-tolerance bearing housing axial clearances shall be corrected by machining, or by replacing bearing assembly components.

j. Plain seal clearances between the shaft and bearing housing can be restored by boring and re-sleeving the housing. Non-metallic bearing housing seals shall be replaced and labyrinth type seals either repaired or replaced.

k. If the bearing hub-to-shaft fit is too loose, it shall be corrected by either restoring the shaft dimensions to specification or by manufacturing a new hub to specifications or by a combination of the two.

4.2.1.4.2 Sleeve and Tilting Pad Bearings

The following procedures shall be followed when reconditioning or repairing sleeve and tilting pad bearing assemblies:

a. With the bearing shells installed, bearings shall be checked for tolerances, concentricity and nip. On fitting of the rotor into the stator, bearing clearances and lay shall be checked to ensure correct fitting of the shell.

b. Blueing and plastic gauges are to be used if the lay is not greater than 90%. The responsible engineer is be contacted for permission before any scrapping takes place. With the modern manufacturing techniques, scrapping should not be necessary. All joints, inlets, drain plugs etc. shall be sealed to prevent oil leaks. Copies of the blue prints are to be provided as part of data pack, together with copies of the measured bearing tolerances.

c. Minor white metal scratches shall be repaired by polishing the damaged surfaces with a polishing pad such as Scotch-brite ® cloth. Tilting pad bearings shall have their minor scratches lapped or rubbed with Scotch-brite® to remove high points.

d. Major scoring and wipes on the white metal surfaces shall be repaired by replacing, or re-metalling the bearing. If the bearing needs to be re-metalled or replaced, an ultrasonic test shall be conducted on the re-metalled or replacement bearing white metal before bearing installation. The pads for tilting pad bearings shall be replaced, or re-metalled as a complete set. The acceptance criterion for such testing is at least 95% bonding over the journal area and 100% bonding on the edges.

e. Out-of-tolerance bearing housings shall be machined if under size, or built up if over size.

f. Damage or excessive clearances in labyrinth seals shall be corrected by repair, or replacement of the seals. If the motor manufacturer's seal design clearances are not available, the diametrical clearances shall be restored to values that are 0.0508mm to 0.1016mm greater than the bearing clearance.

g. Oil rings and pick-up discs shall be checked for roundness and wear. Damaged oil rings in sleeve bearings shall be replaced. If the ring is a split ring, the screw holding the two halves of the ring together shall be tightened and locked in place by pining or some other means. A dye-penetration test is to be conducted on each split half of the ring to determine the existence of cracks.

h. Unless the bearing is specifically designed for a double oil ring, all double oil rings are to be replaced with a single oil ring.

i. Replace any oil ring sight glass that is no longer transparent, or has some other defect.

j. If the thrust runner-to-shaft fit is too loose, restore the shaft dimensions by plating and/or micro-welding the hub bore and machining it for the desired dimensions. Machining and lapping procedures may be used to restore thrust bearing thrust runner surfaces. Alternatively, a new thrust runner may be manufactured with correct dimensions.

k. Any sediment, metal particles, or other contaminants shall be removed from the oil reservoir with a dry, lint free, cloth.

l. Oil reservoirs shall be leak-checked after necessary repairs and final inspections have been completed. To test for leaks, fill the reservoir with a low viscosity cleaning fluid such as Varsol ® and inspect external surfaces and connections. After leak tests, Varsol® shall be drained and any remaining residue shall be removed by wiping with a dry, lint free, cloth.

m. The oil reservoir shall be thoroughly cleaned of oil and grease and painted with a white, two-part, epoxy.

n. Any debris trapped between cooler fins shall be removed.

o. If leaks are present, or if there is thinning of the bearing cooler tube walls, the cooler shall be replaced with a new cooler. If the failure mechanism is found to be erosion/ corrosion, a better corrosion resistant material such as stainless steel should be considered for the replacement. All repaired, or replacement coolers shall be pressure tested.

p. Replace all damaged bearing insulation components including insulating sleeves, washers, bearing anti-rotation pins with new components made from NEMA G10 or G11, or equivalent, epoxy glass material.

4.2.1.4.3 Grease relief systems

The following is applicable for bearing grease relief systems:

a. If no grease release system exists on the bearings the *Repairer* shall provide the *Employer* with a proposal for approval. The *Repairer* will implement the approved solution.

b. Grease release systems should be designed to ensure grease is not discharged into the motor, the motor fan or slip-ring enclosures.

c. Extended grease nipples are to be installed where applicable.

4.2.1.4.4 Water Cooled Bearings

The following is applicable to water cooled bearings:

a. The cooling coil and cooling water jackets shall be cleaned and checked for blockages. New gaskets are to be fitted and pressure is to be checked for leakages.

b. Cleaning of the cooling coils is to be performed by means of an appropriate method. Chemical cleaning is preferred.

4.2.1.4.5 Oil Gauge Glasses

The following is applicable to oil gauge glasses:

a. Oil gauge glasses are to be inspected for correct functionality.

b. Gauge glasses are to be replaced at the sign of cracking.

c. All leaks are to be repaired by replacing the relevant seals and O-rings.

d. Oil levels are to be properly and correctly indicated on the oil sight glasses. Indications are to include standing and running oil levels.

e. Oil level markings on any original gauge glasses are to be verified for correctness. Markings are to preferably indicate both minimum and maximum oil levels.

4.2.1.4.6 Thrust Bearings

The following is applicable to thrust bearings:

a. The removal of the thrust collar shall be carried out by hydraulic methods. Heat shall not be applied to the thrust collars, directly or indirectly, during removal or fitting. Refitting shall take place in a similar fashion. The run-out of guide and thrust faces is to be checked to ensure correctness.

b. The thrust collar shall not be rested on the thrust face without adequate protection. Surface finishes of thrust guide faces is to comply with the manufacturer’s tolerances.

Note: Bearing manufacturer specified minimum running speeds and run down times is to be adhered to.

4.2.1.5 Accessories

a. All failed space heater elements shall be replaced with new elements with the same Wattage, Voltage, and surface temperature rating. Unless otherwise agreed between the *Repairer* and *Employer*, new space heaters shall be rated to operate at half their rated voltage and connected in parallel.

b. All damaged or aged heater wiring shall be replaced with high temperature insulated wires, with the same or increased conductor size.

c. Rewired space heater circuits shall be checked to verify conformance to original circuit configuration.

d. All damaged bearing RTD wiring shall be replaced, provided the RTD element indicates the correct temperature.

e. After repairs, bearing temperature detectors shall be checked for accuracy.

4.2.2 Motor Assembly

All tests and inspections conducted as part of the motor assembly shall be recorded on a motor build report. The procedure for these checks and tests during motor assembly are contained in the section Inspection and Testing. General requirements are as follows:

a. Secure bolts by coating threads with a durable anti-corrosion/anti-seize compound. All bolts installed during assembly of motor components or motor component attachments shall be tensioned with proper bolt stretch via torque wrench or other acceptable means.

b. Clean conditions shall be practiced to ensure no materials that would affect motor performance are left inside the motor, and shaft landing surfaces shall be protected from damage due to mishandling.

c. Care should be taken when assembling bearing cooler pipe connections to prevent twisting the cooler inside the oil reservoir.

d. When specified in the repair SOW, the concentricity of bearing bracket mounting flanges, bearing brackets and bearing housing bores shall be checked in relation to the stator bore.

e. Measure the amount of rotor lift on Vertical Motors with tilting pad bearings.

f. Fill each bearing with the type and grade of oil specified. Check that the standing oil level is clear and oil is clearly visible on all its site glasses. Oil leaks before, during, and after motor testing are not allowed.

g. Conduct the no load test on all motors as per subsection 4.4.5 Routine Test.

h. If specified in the SOW, a full load performance test shall be performed on the motor as per the performance procedure.

4.2.3 Painting

Painting shall be done in accordance with the following procedure:

a. Surface preparation shall involve the removal of all corrosion, oil, grease, dirt, and old paint with a combination of commercially accepted cleaning agents, abrasive blasting, power tool, and hand tool cleaning. Metal surfaces shall have sufficient roughness to provide proper adhesion of new paint.

b. At least one primer coat and two finishing coats of compatible outdoor paint shall be applied in accordance with the paint manufacturer's instructions. Two-part epoxy type paint is preferred because of its toughness and durability.

c. The finishing colour for external metal surfaces shall be Emerald Grey (G29) or other as specified.

4.2.4 Repaired Motor Delivery

All motors shall be prepared for shipment and delivered as per the SOW and Eskom 240-56361435. If the motor is to be sent into storage, such shall be in accordance with Eskom 240-56360387. The following is required:

a. Motors shall be delivered to site after the *Employer*'s acceptance that the repair SOW has been satisfactorily completed. Any motor delivered before the *Repairer* receives confirmation of acceptance may, at the *Employer*'s discretion, be returned to the *Repairer* without any cost to the *Employer*.

b. The *Repairer* shall arrange a motor delivery date, time, and location with the *Employer*.

c. All documentation regarding work performed on the motor shall be delivered with the motor. Documentation shall include reports of results for all tests performed, whether the tests are specifically required within this document or not.

d. The *Employer* reserves the right to inspect the motor and transport upon delivery and, if the delivery is found not to be in accordance with applicable specifications, return the motor to the *Repairer* without any costs to the *Employer*.

e. The *Employer* shall provide necessary resources for the motor to be off-loaded from the *Repairer* 's transport.

4.3 EMERGENCY REPAIRS

The requirements of the normal repair procedure are applicable to emergency repairs, the difference being the duration for the requirements to be fulfilled. The *Employer* may classify the motor to require emergency repairs. Having classified that the motor requires emergency repairs, the motor repair/ refurbishment strategy to be utilised shall be determined by the relevant Business Unit and shall be agreed upon by the relevant technical personnel, the end users and the respective commercial departments.

4.4 INSPECTION AND TESTING

Tests and checks shall be performed in accordance with applicable sections in the two phases of repair. If certain results are unacceptable, the *Repairer* shall notify the *Employer* to discuss viable solutions.

a. During the course of repair, the *Employer* may inspect the work at hand to ensure the methods and materials employed are satisfactory. The relevant QCP is to include agreed test criteria, hold points and inspection points.

b. On completion of work, the machine shall be inspected and tested by the *Repairer* to the satisfaction and requirements of the *Employer*. Prior to contacting the *Employer* to arrange a date for witness testing, the *Repairer* shall have satisfied the *Employer's* requirements of a successful refurbishment/repair.

c. Appropriately qualified personnel are to be used for diagnostic testing, inspections and report compilation. The reports are to form part of the quality documentation for the repair.

4.4.1 Test Reports

a. Motor test results shall be recorded on the *Employer's* standard forms for routine tests and performance tests as specified in Eskom Standard 240-50237155 Appendix E and Appendix F. *Repairer* may use their own standard report forms, but the forms must be amended or supplemented, as needed, to clearly and completely cover any reporting items required by the *Employer's* standard forms. Use of *Repairer* standard forms shall be approved by the *Employer*.

b. The *Repairer*'s test reports shall include the results of all tests performed, whether the tests are specifically required herein or not.

4.4.2 Electrical Tests

It should be noted that some of the tests listed below are only required if specified in the SOW.

4.4.2.1 Safety precautions

The following precautions shall be observed when conducting electrical tests.

a. Ensure that the stator windings are completely discharged prior to conducting any electrical test. It is not safe to begin testing before the discharge current is zero and there is no discernible return voltage (less than approximately 20 V) after the ground is removed from the stator. After completion of the test, the winding should be discharged through a suitable resistor, sized to limit the instantaneous current to 1 A.

b. The leads between the test set and winding must be appropriately insulated and spaced from ground. To avoid measuring stray currents, the leads may be shielded.

4.4.2.2 Stator Winding Tests

4.4.2.2.1 Insulation Resistance (IR) and Polarization Index (PI) Tests

a. Insulation Resistance (IR) tests shall be conducted with a capable megohm meter equipment which will on output provide a plotted trend of the measured insulation resistance as a function of time, throughout the entire duration of the measurement of the IR_{1min} and IR_{10min}. From the trend the Dielectric Absorption Ration (DAR) and Polarization Index (PI) will be calculated by measuring and recording the 30-second reading (IR_{30sec}), 1-minute reading (IR_{1min}), and 10-minute reading (IR_{10min}). The DC megohm meter shall be capable of developing and displaying test voltages sampled at no longer than 5-second intervals. Test voltages for motors within stated range of rated line-line voltages for 3-phase, line-to-ground for single phase, and direct voltage for DC or field windings are recommended in Table 1.

Table 1: Recommended Insulation Tester Voltages

Motor Rated AC Voltage [V]	DC Test Voltage [V]
V < 1000	500
1000 ≥ V ≤ 2500	1000
2500 > V ≤ 5000	2500
5000 > V ≤ 12000	5000
V > 12000	10000

b. Ensure that the winding temperature is above ambient air dew point. If the dew point cannot be determined, this test should be conducted when the winding temperature is at or above that of ambient air.

c. Document the following test conditions:

- Ambient temperature,
- relative humidity,
- dew point,
- stator winding temperature, and
- test voltage, as per Table 1.

d. Each phase should be isolated and tested separately with the other phases grounded, where possible.

e. Insulation resistance readings are to be taken after applying the test voltage as indicated in Table 1. IR_{1min} is to be temperature corrected to a common base of 40°C using the following equation:

$$R_c = K_t \times R_t$$

where,

R_c = Insulation resistance corrected to 40°C,

R_t = Insulation resistance at Temperature t°C, and

K_t = Insulation resistance temperature coefficient at temperature t°C obtained from Figure 1

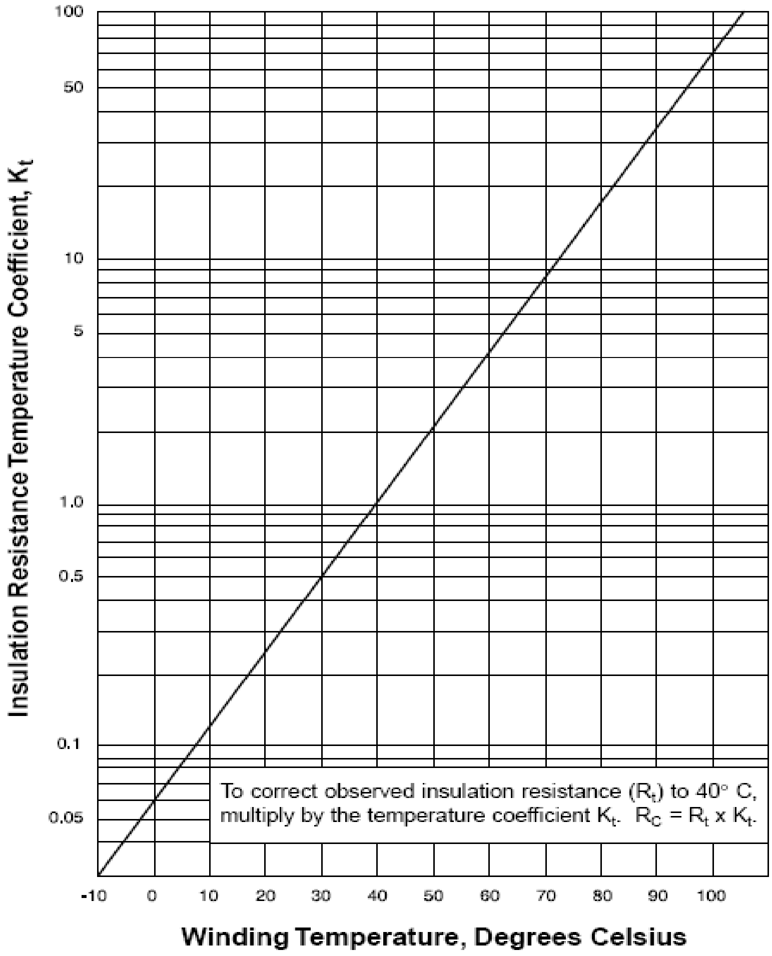

Figure 1: Insulation Resistance Temperature Correction

f. Table 2 provides guidance for conducting the DC insulation resistance test and acceptance criteria. It shows the minimum corrected IR_1 values applicable to all phases-to-earth (entire winding). Minimum IR_1 on one phase-to-earth, with the other two phases earthed, should be double that of the entire winding.

Table 2: Insulation Resistance Test Acceptance Criteria

Motor Rated Voltage [V] (1)	Pre-1970 Winding Minimum IR_1 @ 40°C [MΩ]	Modern Form-Wound Winding Minimum IR_1 @ 40°C [MΩ] (4)	Minimum PI (2)	Minimum DAR (3)
< 1000	kV+1 (5)	5	2.0	1.5
3 300		100		
6 600				
11 000				
15 000				

Notes:

1) The motor rated voltage is based on Eskom standard line to line voltages
2) The Polarisation Index, $PI = \frac{IR_{10}}{IR_1}$
    - PI shall be disregarded if the corrected IR_1 is above 5 GΩ for modern form-wound windings.
    - High PI is indicative of thermal deterioration on pre-1970 windings typically made of asphaltic mica insulation.
3) The Dielectric Absorption Ratio, $DAR = \frac{IR_1}{IR_{30}}$ is the quicker version of PI
4) For insulation that consists of mica paper tapes bonded with epoxy resin.
5) Applicable to most windings made before 1970

4.4.2.2.2 Stator Winding Resistance Test

The following is required for stator winding resistance tests:

a. A bridge-type instrument or digital ohmmeter capable of measuring and displaying milliohms shall be used to record the three line terminal-to-terminal stator winding DC resistance values, i.e., R_{UV}, R_{VW} and R_{WU}. Letters U-V-W may be substituted by A-B-C, depending on the terminal notation.

b. Document the stator winding temperature during the test.

c. Correct the measured values to 20°C using the following equation:

$$R_{LL,20} = \left(\frac{R_{LL,T}}{(1 + 0.00392(T - 20))} \right) \Omega$$

where;

$R_{LL,20}$ is the terminal-to-terminal winding resistance correct to 20°C,

$R_{LL,t}$ is the measured terminal-to-terminal winding resistance at t°C,

d. Calculate the percentage DC resistance imbalance ($R_{imb.}$) using the following equation:

$$R_{imb.} = \left(\frac{R_{Max.\,Deviation\,From\,Average} - R_{Average}}{R_{Average}} \right) \times 100\%$$

e. The acceptance criteria for a new winding is that $R_{imb.}$ should not exceed 1.0%. If this value is exceeded clearance should be obtained from the *Employer* to determine a method to proceed.

f. Motors with either duplicate or parallel winding terminals shall have the winding resistances measured on one terminal box with all internally connected line terminals on the two terminal boxes shorted to each other, e.g. U1-1 shorted to U1-2, with leads between the two terminal boxes. This method of measurement shall prove the correct phasing of internal line terminal connection between the terminal boxes.

- Deviation from winding resistances measured without external terminal short circuiting and/or imbalance above acceptance criterion is indicative of incorrect phasing on internal line terminations

4.4.2.2.3 AC High Potential Test

a. The Hi-pot test is to be performed upon written request. All AC Hi-pot tests shall be witnessed by the *Employer*.

b. The high-voltage test procedure shall comply with IEC Standard 60034-1.

c. A 50 Hz AC Hi-pot shall always be performed after a motor rewind. Reconditioned windings may, when specified by the *Employer*, be conducted.

d. The test shall be performed on either the complete stator winding or individual phase windings. Unless otherwise specified in the SOW, only one of the two methods shall be used. Where the star point is accessible, it shall be disconnected for the individual phase windings to be tested with the other two grounded.

e. The stator frame and winding temperature detectors, if fitted, shall be grounded before performing the test.

f. Hi-pot testing shall be performed only after the IR and PI tests have been successfully conducted.

g. It is the *Repairer*'s responsibility to determine the minimum AC Hi-pot test set kVA rating based upon the capacitance of the winding.

h. The applied test voltage for an AC Hi-pot test shall be as follows:

- $(1.5 \times V_{LL})$ for 1.0 minute on reconditioned and repaired old windings, i.e. 4950 V on 3300 V and 16500 V on 11000 V windings.
- $(2 \times V_{LL} + 1000 \quad V)$ for 1.0 minute on new windings, i.e. 7600 V on 3300 V and 23000 V on 11000 V windings.

i. Perform IR and PI tests after the AC Hi-pot test to verify the insulation system was not damaged during the test.

j. If the stator fails the AC Hi-pot test after a rewind, the new winding shall be completely replaced with a properly processed winding. All expenses involved with replacing the newly rewound stator shall be the responsibility of *Repairer*.

d. For motors with internally connected windings, which have only three line–ends accessible, a single high voltage test shall be applied between the windings and the earthed frame.

e. For motors having both ends of each phase winding brought out to accessible terminals, the test voltage shall be applied between each phase and earth, with the phases not under test also connected to earth.

f. For motors in service, the test is to be performed at line voltage for star connected motors.

4.4.2.2.4 DC High Potential Test

The DC hi-pot test is an alternative test to AC hi-pot that shall be performed after a rewind and repair. All requirements for AC hi-pot are applicable to the alternative DC Hi-pot test, with the following exceptions:

a. Reconditioned windings shall, when specified by the *Employer*, be tested using the DC Step Voltage Test described in the next section.

b. The applied test voltage for DC Hi-pot test shall be:

   $1.7 \times \left(2 \times V_{LL} + 1000\,V\right)$ for 1.0 minute on new windings, e.g. 12920 V on 3300 V and 39100 V on 11000 V windings.

4.4.2.2.5 DC Step Voltage Test

The DC Step Voltage test is to be performed upon request of the *Employer*. All requirements for DC hi-pot are applicable to the DC Step Voltage test, with the following exceptions:

a. Plot the leakage current versus applied voltage on a graph. An uncontaminated and/or undamaged insulation system has an almost linear curve that should develop as voltage is ramped, or stepped up to the final value given in Table 3 below.

Table 3: Recommended DC Step Voltages

Motor Rated Voltage	First DC Step Voltage	Voltage Steps after Initial Step Voltage	Number of Steps	Final 1.0 Minute DC Hipot Voltage	Final Hipot Value as % of DC Equivalent of Motor Rated Voltage*
3300	2000	600	9	8700	155.1%
6600	5000	1500	8	17000	151.5%
11000	10000	2000	9	28000	149.7%
15 000	14000	2500	8	38000	149.0%

* Equivalent DC voltage = 1.7 × AC value

b. If the leakage current increase is rapid and non-linear with respect to applied voltage, stop the test immediately and prior to reaching the final test voltage. This indicates that the motor either requires cleaning and dry-out or it has a ground insulation defect.

c. After cleaning and drying, repeat the IR and the DC Step Voltage tests. If the DC Step Voltage test cannot be passed after cleaning and drying the windings, the ground insulation defect shall be investigated.

4.4.2.2.6 Impulse Testing

All the stator coils of motors which have been completely rewound shall be subjected to inter-turn insulation tests. All coils installed in the stator shall have interturn insulation surge/impulse tested in accordance with IEEE Std 522, while tests conducted on sample coils shall be conducted in accordance with SANS IEC 60034-15.

a. A type test on a sample coil after inserting it into the stator slots. This coil shall be subjected to four impulses at voltages having peak values of 1kV, 2 x VL and 4x VL (where VL = rated line voltage). The pulse traces should all have the same pattern.

b. Routine tests should then be carried out on all coils after inserting and wedging them into the stator slots. Each coil shall be subjected to 4 impulses having peak values of 2 x VL. The pulse trace in each case shall be compared with the pulse trace obtained for the type test at 1kV. If a difference is observed, a 1kV impulse should be applied to the coil in question. If the difference is still observed, the coil shall be replaced.

c. The impulse wave shall have a maximum rise time of 0,2µs and compliance to this requirement is to be checked by an *Eskom* approved testing authority.

d. Inter-turn insulation tests are to be performed on old insulation during the initial assessment of a motor.

4.4.2.2.7 Dissipation Factor (Tan-δ) and Capacitance Tests

a. Tan Delta tests shall be conducted on each winding insulation by measuring and recording power/dissipation factor and capacitance, while the other two phases are shorted to ground, for a completely cured windings. An appropriate size 50 Hz AC test unit to provide the required measurements at applied voltage from 20% to 100%, at 20% increments, of motor rated line-to-line voltage shall be utilised. The accuracy of the bridge shall be, at worst, 1%.

b. Test conditions that are to be recorded are; ambient temperature, relative humidity, stator winding temperature, and test voltage at each test point.

c. The characteristics to be calculated and evaluated for each winding are;

- Tan-δ at 20% and 100% of rated voltage,
- The change in Tan-δ (ΔTan-δ) between two incremental points from 20% through to 100%,
- Tan-δ Slope (Tip-up) value from the 20% and 60% voltage points, and
- The change in Capacitance (ΔC) between the 20% and 100% voltage data points.

d. The acceptance criteria are as detailed in the Table 4 below.

Table 4: Tan-δ Acceptance Criteria

Item	For individual phases and total winding	For new windings *	For motors in use **
1	0,2Un Tan Delta value	Less than 0,0100	Less than 0,0400
2	1Un Tan Delta value	Less than 0,0300	Less than 0,0800
3	Steps between 0,2Un to 1Un	Less than 0,0060	Less than 0,0100
4	Slope (0,6Un – 0,2Un) / 2	Less than 0,0060	Less than 0,0100
5	Maximum capacitance change 0,2 Un to 1 Un, with 0,2 Un as reference	Less than 3%	Less than 6%
6	Tip up (1Un – 0,2Un)	Less than 0,0200	Less than 0,0400

NB – Tan-δ values stipulated are to be treated as guidelines.

Note:

* It is accepted that the tan- δ acceptance criteria for a specific motor is dependent on factors such as insulation type and motor design. In the event that the *Repairer* is not capable of meeting the criteria specified in Table 4, agreement on acceptance criteria is to be reached prior to commencing with the rewind process. In the event an agreement is not reached the integrity of the rewind process is to be confirmed by means of a motorette. The following will be applicable to the motorette;

- Motorette to be a randomly selected coil from the set of coils manufactured for the motor.
- Motorette installation into the core simulator is to be the same as the installation into the motor. This includes material dimensions and type, slot liner, packers, spacers, etc.
- Core simulator is to have the same dimensions i.e. length, width and depth as the core.
- Core simulator slot width to be within ± 0.05 mm of the core dimensions with the length within 1,0 mm and depth within 0.5mm.
- Cooling slots are to be simulated by cut-outs in the core simulator.
- Wedge materials are to be strapped in place.
- Both sides of the motorette are to be inserted into the core simulator.
- If the machine is manufactured from bars instead of coils, one bar only is acceptable as a motorette.
- Motorette is to accompany the motor throughout the VPI process to ensure similar VPI exposure.
- Rotate curing of the motorette is not a requirement.
- Motorette can be positioned vertically or horizontally in the VPI tank. The orientation is to be the same as the VPI'd machine. When horizontally positioned, the motorette is to be placed as high as possible in the VPI tank.

** Acceptance criteria for motors in service is NOT a criteria for the failure of the insulation system and is NOT intended to serve as an indication of insulation life. Tan- δ readings are required to be trended over time to determine ageing of insulation. Cognisance is to be taken of the insulation state, type and age.

4.4.2.3 Core Flux Test

The iron cores of all stators and rotors being repaired, replaced or rewound shall be subjected by the *Repairer* to a core flux test.

a. Unless otherwise specified or approved the test shall be performed before and after an unwound core is wound and before and after a wound core is unwound. The test shall also be performed by applying a test voltage which will generate a 1,5T flux density at the back of the core. The *Employer* must provide the required V/turn for the test.

b. The core shall be examined for abnormal or uneven heating (hot spots) by means of a thermal camera. Hot spots are any spots 10ºC above the average core temperature after full flux has been applied for 15 minutes. Longer periods for larger cores can be done with Employer's consent.

c. The average core temperature is not to exceed 10ºC above ambient temperature. The core loss should be at least 5 W/kg for a good core. Values ranging from 5-8 W/Kg are acceptable with the core to be verified for any possible mechanical damage. Values from 9-12W/kg can be further substantiated by performing an EL-Cid to assist with decision making.

d. A report detailing the result of the core flux test, the hot spots repair procedure and the feasibility of the hot spot repairs to be provided to the *Employer*.

e. The *Employer* is to approve the repair prior to the commencement of the work.

4.4.2.4 Other Component Electrical Tests

4.4.2.4.1 Space Heater and Temperature Detector Insulation Resistance Tests

a. Insulation resistance of space heaters with voltage ratings of 220 volts and winding temperature detectors shall be measured with a 100V megohmmeter.

b. The minimum acceptable resistance (IR_1) is 10 MΩ.

4.4.2.4.2 Bearing Insulation Resistance Tests

The bearing insulation resistance shall be measured on a stationary motor either during assembly or with the motor completely assembled. Bearing insulation can also be checked while the motor is running during a no-load test.

a. On a stationary motor; disconnect the earthing device on the DE bearing and Megger at 500 V_{DC} between the shaft and earthed frame.

b. On a running motor; measure the voltage between the two shaft ends.

c. Acceptable bearing insulation resistances should exceed one (1) MΩ

d. Shaft voltages should not exceed 100 mV for un-insulated ball and roller bearings, and 300 mV for un-insulated sleeve bearings, whichever is applicable.

4.4.2.4.3 Rotor Bar Test

The Induced Current and Loop Test shall only be conducted on the rotor if rotor bar cracks or breaks, as detected by inspections, are thought to be present. The procedure shall be as follows:

a. Induce AC currents in the rotor squirrel-cage winding by applying a low voltage across the ends of the rotor shaft, or by a core loop test similar to that of the stator.

b. Place iron filings or magnetic paper over the rotor and a clear representation of the bar should be seen. If any discontinuity in the bar or misalignment of two sections of bar appears, this indicates a broken bar.

c. If there is evidence of broken bars, warm the rotor by increasing the applied voltage. This should produce hot spots at the location of a cracked rotor bar, which should be detected and recorded with an infrared scanning device.

d. During the second part of this test, checks are required for lamination vibrations, which are indicative of a loose core.

e. There shall be no rotor lamination vibration or hot spots in the rotor bars or end rings.

The Elcid and bar to bar test may be requested by the *Employer* if so deemed necessary.

a. When a slip-ring motor rotor winding has been repaired and the complete machine is available in the *Repairer*'s works, the rotor open circuit voltage is to be measured and recorded at standstill with the rated voltage applied to the stator.

4.4.3 Mechanical Checks before Assembly

The following mechanical checks and tests shall be performed while the motor is disassembled.

4.4.3.1 Rotor Balancing

All motors being refurbished or repaired shall have the rotor balance checked. In the event of rotor repairs or rewinds, the rotor shall be statically balanced followed by dynamical balancing at rated speed. This is to be performed both before and after any over speed test, where relevant, unless otherwise agreed by the *Employer*. The rotor shall be balanced after all cleaning, testing, inspections and repairs have been completed. This shall be done in a balancing machine to Dynamic balancing standard ISO 1940/1

- G1.0 Balance Quality Grade for motors with 4 or more poles.
- G0.4 Balance Quality Grade for 2 pole motors

b. The following balance weight requirements shall be adhered to for rotor balancing:

- Either the motor coupling half or a half key shall be installed on the shaft extension for rotor balancing.
- Shaft-mounted cooling fans shall be installed for balancing.
- Putty balance weights shall not be used and any putty weights shall be removed.
- All balance weights shall be mechanically attached.
- Attachment of balance weights to fan blades shall be avoided wherever possible.

4.4.3.2 Rotor and Shaft Run-out

The shaft extensions, bearing journals, and rotor body straightness shall have their total run-out measured with the rotor mounted in a lathe, V-blocks or rollers. The acceptance criteria for such run-out measurements are as follows:

a. Shaft extension and bearing journal run-out values shall not exceed 0.025 mm for 2 and 4 pole motors.

b. The bearing journal run-out values shall also not exceed 0.025 mm.

c. Rotor core outer diameter run-outs as measured at both ends and centre shall not exceed 0.127 mm.

d. The maximum run-out on thrust faces of vertical motors, which is measured with the thrust runner mounted on the rotor, shall not exceed 0.025 mm.

4.4.4 Motor Assembly

4.4.4.1 Mechanical Checks during Assembly

4.4.4.1.1 Concentricity

a. Concentricity checks in relation to the stator bore shall be conducted for bearing bracket mounting flanges, bearing brackets and bearing housing bores. This shall be done on all 2-pole motors and, where specified, other motors.

4.4.4.1.2 Ball and Roller Bearings

a. The following checks and measurements shall be made and the results recorded for ball and roller bearings;

- The fit between each bearing inner ring and the shaft, or between the inner ring and the mounting hub, and between the bearing outer ring and the bearing housing.
- There is an axial space between the ball bearing outer ring and the end cap of the bearing housing to allow for shaft growth. During motor re-assembly, this space shall be measured to ensure that it is adequately sized to prevent contact between the bearing and the end cap as a result of shaft growth under load conditions.
- The radial play and axial play acceptance criteria shall be the motor or bearing OEM's design limit.
- These bearings shall be installed as specified in subsection 4.2.1.4.1 Anti-friction Bearings inspection.
- The type and amount of lubrication grease filled in the bearings.

4.4.4.1.3 Sleeve Bearings

a. For sleeve bearings, check and record the following during re-assembly;

- Bearing bore concentricity by performing three sets of measurements at both ends and in the middle of the bearing. At each location take three readings, 120 degrees apart and at the splits, if applicable. All readings shall all be within 0.025mm of each other and the motor manufacturer's bore tolerances, if available.
- The oil ring roundness, measured on three locations that are 120 degrees apart, shall be within 0.127mm of each other.
- The fits between each bearing outer diameter and housing must be within the following limits;

- For thick shell bearings, unless otherwise specified by the motor manufacturer, such fits should be size-for-size to 0.0254 – 0.0508 mm tight.
- For thin shell bearings such fits should be size-for-size to 0.0508 mm loose.

- Bearing bore to shaft bearing journal clearances by using the bore roundness measurements. The acceptance criteria shall be the motor OEM's design limits. If the motor manufacturer's design limits are unavailable, the maximum diametrical bearing shaft journal to bearing clearance shall be in accordance with Table 5.

Table 5: Sleeve Bearing Clearance Acceptance Criteria

Bearing Journal Diameter [mm]	Minimum Diametral Clearance [mm]	Normal Tolerance Above Minimum Diametral Clearance [mm]
25-to-75	0.101	0.0254
75-to-180	0.002/mm of shaft diameter	0.0508
180-to-250		0.127
250-to-500	0.0005/mm of shaft diameter +0.381	0.127

- The contact between the sleeve bearing shaft journal and the sleeve bearing white metal surface, requires verification that there is at least 80% bearing lay in the axial direction, and the lay is on the load carrying portion of the bearing.
  - Bearing scraping shall not be used to meet this acceptance criterion. Re-alignment of the end shields and/or bearings is preferred.
- The shaft to bearing housing seal clearance values by measuring seal bores and using measured shaft diameters. The acceptance criterion, if no manufacturer's values are available, shall be 0.05 to 0.1 mm greater than the bearing diametrical clearance.

4.4.4.2 Mechanical Tests and Checks after Assembly

a. Where possible, the air gap between the stator and rotor shall be checked with feeler gauges at 4 positions 90° apart. The air gap measurement is to be taken at both the drive end (DE) and the non-drive end (NDE). The air gap measurements shall be within ± 10% of the average for motors with 4 or more poles and ± 8% for 2-pole motors. Corrective action taken to restore the air gap to within this limit shall be discussed with the *Employer*.

b. Motors with sleeve bearings, the end-float and magnetic centre shall be checked.

- The total axial end float of the horizontal motor rotor in the bearings shall be measured by manually rotating the rotor on lubricated bearings. The following are specific requirements for rotor end float.
  - The machine bearings should have the minimum end-float not less than the motor manufacturer's design value. If the motor OEM value is unavailable, the minimum end-float shall be in accordance with values in Table 6.
  - If the total end-float is less than the minimum end-float value, modifications shall be made to restore rotor end float to the minimum value.

Table 6: Sleeve Bearing End-float Acceptance Criteria

Motor Rating [kW]	Number of Poles	Minimum End Float [mm]
Below 200	2	6
200-to-375	2	10
375 and below	4 and above	6
Above 375	All speeds	10

- Shaft end float limits and magnetic centre shall be marked with indelible lines on the shaft extension or tilting pad guide bearing. Labelling, either on the motor DE bearing or end-shield, the machine rotor end float and magnetic centre in millimetres.
- The running motor magnetic centre shall not shift from either side of the geometric centre by more than 20% of the total end-float.
- The magnetic centre line should be provided with a sharp marker from the bearing end cap or dust seal cover, and dimensions of the centre line to the bearing end-cap or dust seal cover shall be recorded and marked on the motor.

4.4.5 Routine Test

4.4.5.1 Pre-run electrical checks and tests

The following electrical tests/measurements shall be performed on the motor after assembling and prior to the no-load test-run to be witnessed by the *Employer*. These tests shall also be witnessed by the *Employer* and recorded on the pre-run test data section of the Routine Test Certificate.

a. Stator Winding Resistance and percentage imbalance;

b. Stator Winding IR, DAR, and PI,

- If the measured and corrected IR_1 and calculated PI are less than specified critical limit values, the windings must be dried prior to motor testing. If the measured values are within 120% of critical acceptance criteria, the motor may be energised for test-running and the insulation resistance tests subsequently checked at the completion of the test-run.
- Unless otherwise specified in the Contract, the acceptance criteria for the motor to be delivered, regardless of other test results, is that IR_1 and PI test results must exceed minimum acceptable values as in Table 2.;

c. Space Heater and winding ETD IR tests and functional checks;

d. Bearing RTD/Thermocouple Functional Checks;

e. Bearing insulation IR (if applicable);

f. Rotational direction with supply phases L1, L2, and L3 connected to U1, V1, and W1. When viewed from DE, the direction of rotation shall be clockwise.

g. Locked rotor.

4.4.5.2 Test Power Supply and Instrumentation Quality

Due to the effect of power supply quality on the electrical machine performance, it is essential that a suitable source of power and careful measurement with accurate instrumentation are employed for correct data and performance to be obtained. The test facility shall therefore have the power supply source and instrumentation that is capable of meeting the following requirements throughout the test duration;

a. The harmonic distortion coefficient, THD, shall not exceed 0.05.

b. The voltage unbalance shall not exceed 0.5%.

c. The frequency shall be within ±0.5% for routine test, and ±0.1% for performance test of motor rated frequency. The power supply frequency range is, therefore, limited to 49.75-to-50.25 Hz for routine tests, and 49.95-to-50.05 Hz for performance test.

d. Variations in frequency during a test shall not exceed 0.33% of the average frequency.

e. Power supply quality shall be monitored, and automatically controlled throughout the test duration. The supply conditions shall be recorded throughout the tests, and such records must form part of the motor test record.

f. The accuracy of instrumentation used to measure test data shall be in accordance with SANS IEC 60034-2-1 requirements.

g. The capabilities of vibration measurement instruments shall include the following;

- Can measure displacement, velocity, acceleration, and phase that require at least two channels.
- The software must be able to convert the vibration time waveform between acceleration and velocity.
- Minimum zoom factor of 10 to enable high-resolution spectral analysis. The analyser shall therefore be able to permit time period (maximum frequency) settings of 12 000 CPM (200 Hz) for 1 600 lines of resolution by machine speed.
- Log amplitude scale
- Wide frequency response range of 0 Hz – 20 kHz, as a minimum, for standard vibration measurements. To reliably detect all calculable rolling element bearing defect frequencies, high-frequency vibration analysis instruments that have a frequency response range of 25 kHz – 36 kHz are required.
- Plots that can be produced include;
    - Time waveforms
    - Plots of overall vibration amplitudes
    - Vibration amplitudes in specific frequency bands
    - Trend plots
    - Bode plots
    - Vibration spectrum and overall vibration in one measurement
- Recording of run test data shall be computerised and automatically transferred from the measuring instrument to the test report, without human interference.

4.4.5.3 No-load Run

All motors shall be run uncoupled with either the half-key or coupling fitted at rated frequency and voltage in accordance with SANS IEC 60034-2-1 to determine constant losses and other performance parameters.

a. The routine test run shall be conducted with the motor completely assembled.

b. Bearings shall be lubricated and cooled as they are designed to be in service, i.e. flood lubrication systems.

c. Snapshot measurements that are to be recorded every 15-minutes, with the first set as soon as the motor testing power supply requirements are met, are;

- Input power,
- Line voltages,
- Line currents,
- Shaft speed,
- Supply frequency,
- Bearing temperatures and bearing coolant inlet and outlet temperature, and
- Winding temperature from the highest reading ETD, and winding coolant inlet and outlet temperatures.

d. The test run shall be long enough to allow the motor to reach stability, which is when bearing temperatures and no-load losses have reached equilibrium.Motor stability shall therefore be considered reached when, at two successive 30 minute intervals;

- The no-load power input at the same voltage varies by not more than 3%, and
- The change in bearing temperatures (ΔT), taking coolant temperature changes into account, is within 1°C.

e. Cold and hot motor horizontal, vertical, and axial vibration measurements shall be taken on both bearing housings.

- For time waveform analysis, standard resolution measurements shall be taken on all directions with the vibration analyser set to 1600 lines of resolution and maximum frequency to at most 30 kCPM (500 Hz). The direction that exhibits the highest standard resolution vibration on either end shall have high resolution measurements taken with the analyser set to no less than 3200 lines of resolution and maximum frequency to at most 12 kCPM (200 Hz).
- Cold vibration levels shall be taken within five minutes of the motor being started. Other vibration measurements must be taken at 30-minute intervals until thermal stability has been reached.
- Hot vibrations measurements shall be conducted when stability has been attained.
- Acceptance criteria for bearing vibrations with the motor solidly bolted to the floor are as per Table 7.

Table 7: Bearing Vibration Acceptance Criteria

Overall vibration levels shall not exceed	No. of Poles
2 mm/s	2-pole motors
1.6 mm/s	4-pole motors
1.2 mm/s	6-pole motors
1.0 mm/s	8-pole motors
0.8 mm/s	10-pole motors
0.5 mm/s	18-pole motors

  - The change between cold and hot vibrations shall not exceed 20%.
  - Vibration spectra for rolling element bearings shall not show any calculable bearing defect frequencies.

f. The acceptance criteria for bearing temperature rise when the motor has reached stability are;

- For Ball and Roller Bearings;
  - 35°C on motors with 4 or more poles
  - 40°C for 2 pole motors.
- For Sleeve and Tilting Pad Bearings;
  - 45°C for vertical motors when measured by the ETD on thrust pads,
  - 30°C for on motors with shaft diameter less than 70 mm,
  - 40°C for 2 and 4-pole motors with shaft diameter between 70 and 100 mm,
  - 30°C for 6-pole and slower motors with shaft diameter between 70 and 100 mm,
  - 45°C for 2 and 4-pole motors with shaft diameter above 100 mm,
  - 35°C for 6-pole and slower motors with shaft diameter above 100 mm,

g. Other measurements and checks that shall be conducted and recorded during the rated frequency and voltage test run are;

- Shaft Voltage,
- Bearing oil and grease leaks,

h. Mechanical Tests and Checks After Assembly (Sub-section 4.4.4.2) No-load loss separation test shall be conducted after all required measurements at rated voltage and stability have been recorded. Recording of winding temperature, average line voltage and current, and power input at rated frequency and at voltages ranging from 120% of rated voltage down to the point where further voltage reduction increases the current.

i. To end the test-run, the following measurements shall be conducted during the motor rundown when it has been de-energised;

- The run-down time for 2-pole motors shall be recorded and abnormal values resolved to the *Employer*'s approval.

- The total end-float for horizontal motors with sleeve bearings.

j. Electrical tests that are to be conducted on a hot motor after the test run are;

- Stator winding Insulation Resistance, Dielectric Absorption (DA), Polarization Index (PI) before and after the following test,
- Stator AC or DC Hi-pot.
- DC Step Voltage Test (if requested)

k. On completion of the bearing run, the sleeve bearings shall be opened up for inspection to verify that there is at least 80% contact between the journal and the white metal surface in the axial direction in the loading area of the bearing. Bearing scraping shall not be used to meet this criterion.

4.4.6 Performance Test

Performance tests shall be carried out to refurbished/repaired motors on written request from the *Employer*.

a. The motor shall be loaded, as per preferred loading method, to 25%, 50%, 75%, 100%, 115% and 130% of rated capacity to determine the efficiency at each load point. The loading shall be in descending order, i.e. from highest to lowest load points.

b. The motor efficiencies shall be determined with the machine at the specified temperature.

c. The temperature rise test shall be conducted on a motor loaded to 100% of its rated capacity.

d. Type tests shall consist of the following measurements/calculations:

- Stator winding temperatures;
- Rated load slip;
- Rated load stator winding and bearing temperature rises;
- Three-phase locked rotor current and torque;
- Speed/torque and speed/current characteristics; and
- Vibration at full load if possible.

e. The permissible temperature rise for all motors shall be in accordance with limits specified in the Thermal Class section. The final temperature and the slip or speed at the reduced voltage shall be recorded. Where it is not possible to load a motor fully in the works, the *Employer* may accept the “mixed frequency” method of temperature rise testing provided the manufacturer can justify the results obtained by this method. A partial load test may also be used subject to the same stipulation. If approved, the temperature rise test may be done on site.

f. The stator winding temperature used to calculate the rated load temperature rise shall be determined from both the rated test resistance method (the Resistance Method), and the directly measuring ETDs (the ETD Method). Both methods shall yield temperature rise within acceptable limits for the specified Thermal Class for motor acceptance.

g. If modifications have been performed to a terminal box, it is required that the terminal box has been type tested according to the relevant regulations and standards and is accompanied with a type test certificate.

4.4.6.1 Thermal Class (Temperature Limits)

a. Stator windings shall be insulated with a Class F (155°C) or higher insulation system that has been proven by usage or tests as per applicable parts of SANS IEC 60034-18.

b. Unless otherwise specified in Technical Schedule-A, the winding temperature rise (*T*) at rated output shall not exceed 80ºC (Class B Insulation System), as measured using the resistance method, subject to the following:

- The reference coolant temperature on which to base the design is either 40ºC or more. The reference coolant temperature shall not be less than 40ºC.
- The design reference coolant for machines with primary and secondary coolants shall be the secondary coolant, with temperatures as stated above.

c. Both the resistance and ETD methods shall be used to determine winding temperatures as per SANS IEC 60034-1. If the resistance method cannot be conducted by the *Repairer*, the ETD method may be approved for use as the only method provided that the ETD location can be proven, through the *Employer* witnessed infrared thermographs during the test, to be at the hottest part/s of stator components.

d. The *Employer* reserves the right to reject a motor where any of the two methods show a rise above the contracted winding temperature rise.

e. The temperature differential between same components that are in the same position shall not exceed 2°C. The temperature differential between all stator components shall not exceed 5°C. The *Employer* reserves the right to reject a motor with thermal scans that show temperature differentials above the stated limits.

f. Test facilities shall be equipped with calibrated infrared thermal imaging camera/s. The *Repairer* shall conduct thermal image scans of all visible running motor components, including open (removed heat exchanger) stator windings and core, during routine and performance testing. These thermal images shall form part of the motor test reports.

5 RECORDS

Each Motor repair shall generate the following records.

a. Records to be kept by the *Employer* for the life of the Station shall include;

- Motor Breakdown Report. An example is provided in APPENDIX D,
- Protection Operating Report
- Assessment Sheet received from the *Repairer*,
- The final repair Scope of Work, including cost thereof,
- All tests and check reports received from the *Repairer*
- Repair vs Replacement Analysis and recommendations, where applicable.
- A copy of Quality records,

b. The *Repairer* shall keep the following records, which shall be submitted to the *Employer* upon completion of the assessment and/or repair contract, for a minimum of five years.

- Motor Breakdown Report, received from the *Employer*,
- Assessment Sheet,
- Repair scope of work,
- Quality records,
- All tests and check reports

6 AUTHORISATION

This document has been seen and accepted by

Name & Surname	Designation
Yokesh Singh	Senior Manager (acting) – PEIC
Prudence Madiba	C&I Senior Engineering Manager – Plant Engineering
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Johan Prinsloo	Medupi Power Station Manager
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Ismail Atiya	Duvha Power Station Engineering Manager
Morongwe Raphasha	Hendrina Power Station Engineering Manager
Malibongwe Mabizela	Kendal Power Station Engineering Manager (acting)
Bongani Mashimbye	Komati Power Station Engineering Manager
Bravance Mashele	Koeberg Power Station Engineering Manager
Zakhele Nkosi	Kriel Power Station Engineering Manager
Harry Sewsunker	Lethabo Power Station Engineering Manager
Ntombenhle Mkhize	Majuba Power Station Engineering Manager
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Lele Masote	Matla Power Station Engineering Manager
Mehendra Maharaj	Tutuka Power Station Engineering Manager
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7. REVISIONS

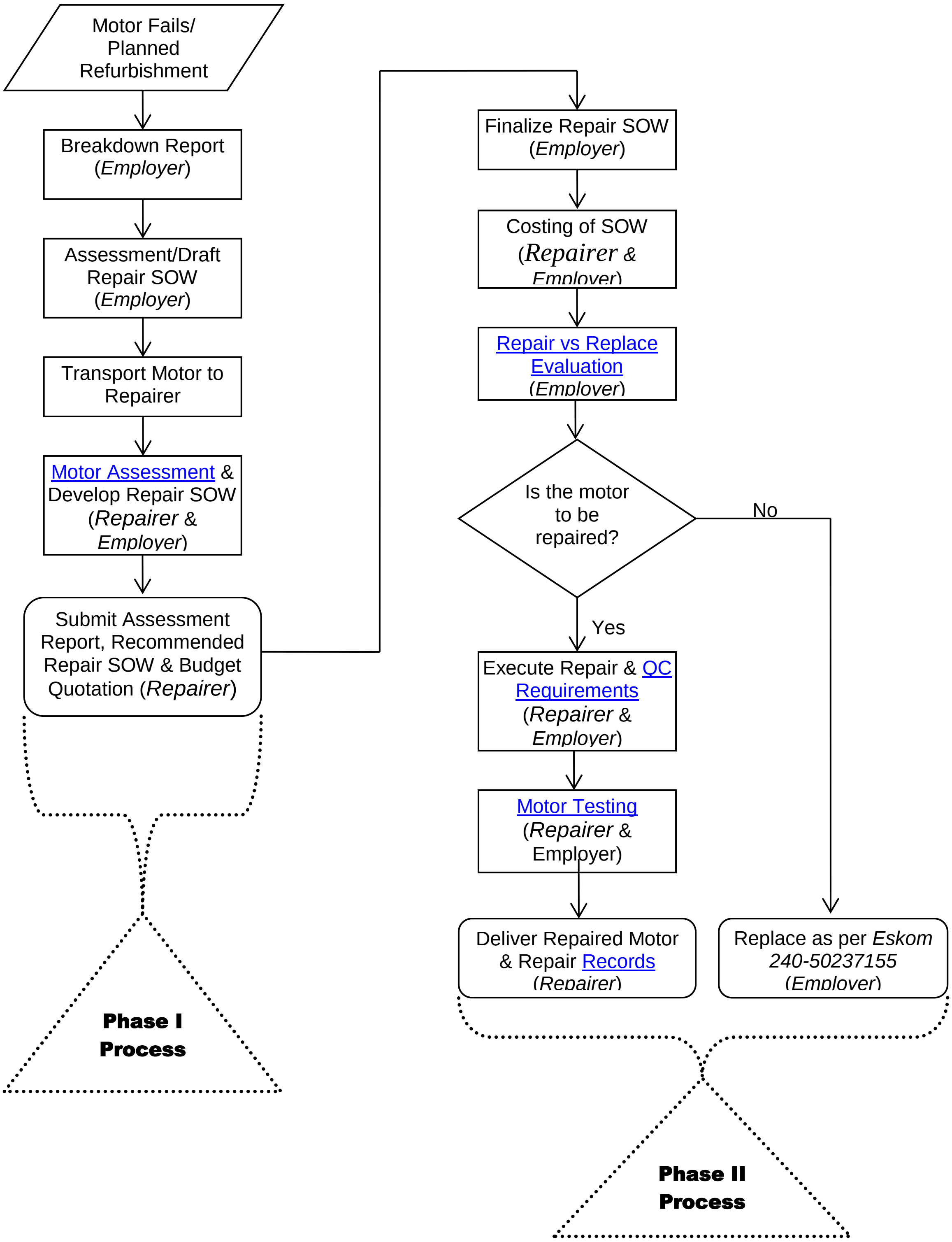
Date	Rev	Compiler	Remarks
December 2013	0.1	P Ruthenberg	Standard converted to Work Instruction
June 2014	0.2	L Mntambo	Informal Review by Motor Care Group
September 2014	0.3	L Mntambo	Informal Review by Rotating Electrical Machinery Study Committee
January 2015	0.4	L Mntambo	Document for Comments Review
January 2015	0.5	L Mntambo	Draft Document for Comments Review
February 2015	1	L Mntambo	Final Document for Authorisation and Publication
August 2017	1.1	M Manyage	Removal of GGS reference, correction of document reference number and signatory page. No Technical Content Changes
September 2017	2	M Manyage	Final Rev 2 Document for Authorisation and Publication

8. DEVELOPMENT TEAM

The following people were involved in the development of this document.

Name	Business Unit
G Brink	Arnot Power Station – Electrical Engineering
L Mntambo	Majuba Power Station – Electrical Engineering
P Khumalo	Group Technology – Production Engineering Integration Coal
P Ruthenberg	Group Technology – Electrical Design and Application CoE
L Muller	Koeberg Power Station – Component Engineering

APPENDIX A: MOTOR REPAIR FLOWCHART



APPENDIX B: ELECTRIC MOTOR REPAIR AND REFURBISHMENT ASSESSMENT FORM

The assessment Form can be found in ESKOM Document 240-87739380

APPENDIX C: DATA PACK INFORMATION FOR REPAIRED AND REFURBISHED MOTORS

C.1 Introduction

C.1.1	The purpose of APPENDIX C is to capture the agreed quality controls to be performed and to identify the acceptance criteria. In addition the agreed hold and witness points are to be captured.
C.1.2	The quality information will be captured as the motor repair progresses through the workshop repair process. Once available, the information is to be forwarded to all responsible parties (e-mail the preferred method) immediately for information and acceptance. Accompanying each procedure shall be a Quality Control Plan and/or a copy of the inspection and test record (ITP). This procedure ensures a step by step quality review and acceptance process.
C.1.3	All the required information is to be available on the date of final motor acceptance.
C.1.4	All acceptance criteria is to be agreed upon by all relevant parties.
C.1.5	Repair shops are to perform all routine tests prior to the *Employer* visit, and is to ensure that all is in order before the *Employer* is called for acceptance/witness testing.
C.1.6	All problems/concerns identified prior to *Employer* witness testing is to be listed in a 'snag sheet'. A corrective action sheet is to be lodged addressing the rectification processes followed.
C.1.7	Previous refurbishment information for the motor at hand is to be available to the *Employer* at the time of testing, for comparison purposes. This information must is to be kept on site and is to be continuously updated.
C.1.8	Reference to Eskom Specification 240-50237155 is required.
C.1.9	Information is to be supplied at the relevant times (See information below).
C.1.10	Information records not catered for on the routine test certificate as per Eskom Specification 240-50237155 is to be recorded on separate sheets.
C.1.11	All process data and QA/QC information is to be e-mailed or faxed as it is captured.
C.1.12	All documents are to include the motor serial number and repair shop job number.
C.1.13	Three data pack copies are normally required.

For each item state if applicable yes or no, and (Date Submitted)

C.2. Motor Details

Item	Details	Applicable Yes	No	Date submitted	Hold / Witness
C.2.1	Record motor details as per Standard Form for Routine Tests Certificate Eskom Specification 240-50237155, Appendix E				

C.3 Incoming Tests

Item	Details	Applicable Yes	No	Date submitted	Hold / Witness
C.3.1	If the motor is in a working condition a routine test is to be performed before any dismantling. (Including vibration analysis with spectrums to diagnose any incoming incipient problems).				
C.3.2	When a motor is received in a failed condition, all effort must be made to determine the root cause of failure. If uncertain, state the possible causes. A short report is required of the symptoms seen including photographs. State the corrective and preventative actions to be taken to prevent re-occurrence. E.g. Even if it has been determined that a phase to earth fault, this needs to be confirmed by performing the 1 minute IR (insulation resistance) prior to stripping or washing.				

C.4. Electrical Data Required

Item	Details	Applicable Yes	No	Date submitted	Hold / Witness
C.4.1	For a stator rewind, stator/rotor rub or wedge rub a core test is required prior to stripping (burn-out) and post burnout : The acceptance criteria for the watts loss per kilogram and hotspots are: • Watts loss: Below 9 watts/kg at 1,5 Tesla. • Hot spots: Less than 10°C rise above average core temperature. • Average core temperature: Less than 10°C rise above ambient.				

C.4.2	The winding resistance acceptance criteria : $\pm 5\%$				
C.4.3	Induction test at rated current, prior to VPI: Check current balance. Acceptance criteria: ……..				
C.4.4	Induction test at rated current, prior to VPI: Check for hot spots on the winding and core. Acceptance criteria: …..				
C.4.5	Induction test at rated current, prior to VPI: Check for hot connections with an infrared camera or alternately with a laser thermometer. Acceptance criteria: …..				
C.4.6	Winding Insulation: IR Acceptance criteria as per Table 1				
C.4.7	Winding Insulation: PI (Polarisation index). Acceptance criteria : PI < 2				
C.4.8	Winding Insulation: Tan δ – perform only upon request. Acceptance criteria as per Table9: Tan-δ Acceptance Criteria				
C.4.9	Winding Insulation: HV test - only upon request.				
C.4.10	Bearing insulation: DE and NDE. Acceptance criteria: Minimum 250 kilo-ohm at 500volt megger after no load test.				
C.4.11	Shaft voltage. Acceptance criteria: 100mV maximum antifriction bearings. 200mV maximum sleeve bearings. Bearing housings earthed				
C.4.12	Heater resistance. Acceptance criteria: …..				
C.4.13	Thermistor / thermocouple resistance. Acceptance criteria: …..				
C.4.14	Performance: No Load - Volts, amps, watts, power factor. Acceptance criteria: ……….				
C.4.15	Performance: Locked rotor – Volts, amps, watts, power factor, torque. Acceptance criteria: ……….				
C.4.16	A single phase test for broken bars is to be performed after the no-load test and locked rotor test. Acceptance criteria: …..				
C.4.17	Final Routine Tests All information as per test sheet, Eskom Standard 240-50237155, Appendix E must be captured. The final routine tests must be done in house first. A snag sheet must be done for all the short comings and these corrected. Hereafter the test records and snag sheet must be sent to the *Project Manager*, prior to customer witness. (e-mailed preferably, alternately faxed) A no load curve is required up to 110% of nominal volts, and as low a voltage as possible.				

C.5. Mechanical Data Required

Item	Details	Applicable Yes	Applicable No	Date submitted	Hold / Witness
C.5.1	Bearings: Bonding certificate. Acceptance criteria:				
C.5.2	Bearings: Dimensions and clearances (As per Drawings provided). Acceptance criteria: …..				
C.5.3	Shaft float. Acceptance criteria: …..				
C.5.4	Magnetic centre. Acceptance criteria: …..				
C.5.5	Concentricity checks: stator bore to stator spigot, end-shield spigot to bearing housing location, bearing housing spigot to bearing bore and bearings OD to ID. Acceptance criteria: …..				
C.5.6	Vibration analysis. (spectrums required: low frequency and high frequency). Confirm acceptance criteria with the power station, upon receipt of an order.				
C.5.7	Vibration analysis: Run down, power off. For all routine final acceptances, after refurbishment or repair, a vibration measurement must be done immediately after power has been cut and compared to the spectrum taken at no load run. This is to differentiate between mechanically and electrically initiated vibrations.				
C.5.8	Record air gap as per drawing provided. Air gap dimensions required prior to dismantling and post final assembly.				
C.5.9	NDT shaft after micro-weld and grinding. NDT certification required (Ultrasonic and particle, surface)				
C.5.10	NDT test fan. (Ultrasonic and surface)				
C.5.11	Measure run down time, after power switch off. (minutes)				
C.5.12	Rotor balancing, as per ISO 1940. Submit calculations of acceptance values. Acceptance criteria :				
C.5.13	Record rotor OD, rotor length, stator OD.				
C.5.14	Record number of stator and rotor slots.				
C.5.15	Record position of stator in the frame from the DE and NDE.				
C.5.16	Drawing: Indicating coil insulation details and details of placement in slot, if motor was rewound. (Dimensioned)				
C.5.17	Assembly check list.				

C.6 Thermal Data

Run motor with temperatures being recorded at 15 minutes intervals. Motor to be run until bearing temperatures have stabilised to within 2 degrees for three consecutive readings. Final bearing temperatures not to exceed the following temperatures above ambient;

Ball and roller bearings;

- 40°C rise for 2 pole motors
- 35°C rise for 4 pole and above motors,

Sleeve and tilting pad bearings:

- 45°C rise for vertical motors when measured by the ETD on thrust pads
- 30°C rise for motors with shaft diameter less than 70mm.
- 40°C rise for 2 and 4 pole motors with shaft diameter between 70mm and 100mm.
- 30°C rise for 6 pole motors and slower motors with shaft diameter between 70mm and 100mm.
- 45°C rise for 2 and 4 pole motors with shaft diameter above 100mm.
- 35°C rise for 6 pole motors and slower with shaft diameter above 100mm.

C.6.1 Bearing run test results:

Item	Details	Applicable Yes	No	Date submitted	Hold / Witness
C.6.1	Measure bearing temperatures				
C.6.2	Measure winding temperatures via embedded detectors.				
C.6.3	Measure frame temperature				

C.7 Visual Inspection Records

Item	Details	Applicable Yes	No	Date submitted	Hold / Witness
C.7.1	Inspect and record oil details: colour, particles, leaks				
C.7.2	Bearing lay (record on drawing provided). Preferably photograph. Acceptance criteria: Go / No Go				
C.7.3	Are all oil rings installed? Are all oil rings rotating?				
C.7.4	Dowel pins. (Pedestal Bearings only - tapered preferred)				
C.7.5	Is terminal box on the correct side viewing from DE?				
C.7.6	If there are two terminal boxes on the motor, are they in the correct position. E.g., are they supposed to be closer to the DE or NDE ?				
C.7.7	Inspect for loose wedges.				

APPENDIX D: MOTOR BREAKDOWN REPORT EXAMPLE

ESKOM POWER STATION MOTOR BREAKDOWN REPORT

Date of Breakdown:		Nature of Breakdown	
Motor Application:		Plant Removed From	
Motor Stock No:		Functional Location:	
Motor Manufacturer:		Serial No:	
Power = [W]	Volts = [V]	F.L.C = [A]	Speed = [RPM]
Did the motor trip? **Yes / No**	What did it trip on?		Was it stopped? **Yes / No**
Motor fault currents during a trip: L_1 =	L_2 =	L_3 =	I_N =

Insulation Resistance Test Results at 2500 VDC on 3.3 kV and 5 kVDC on 11kV Motors:

IR Test on all phases-to-earth; IR_{30} =		IR_1 =	IR_{10} =
Temperature during test; t_{Stator} =	$t_{Ambient}$ =	DA =	PI =

IR Test on each stator winding phase-to-earth with star point removed and other two phases shorted to earth.

$IR_{1\text{-}(U\text{-}phase)}$ =	$IR_{1\text{-}(V\text{-}phase)}$ =	$IR_{1\text{-}(W\text{-}phase)}$ =

IR Test on stator winding phase-to-phase with star point removed.

$IR_{1\text{-}(U\text{-}V)}$ =	$IR_{1\text{-}(V\text{-}W)}$ =	$IR_{1\text{-}(W\text{-}U)}$ =

Winding Resistance Test Results:	$R_{U\text{-}V}$ =	$R_{V\text{-}w}$ =	$R_{W\text{-}U}$ =
Winding Temperature during test °C:		Test set used:	
Previous motor repair tag details; Repairer:		Job No:	Date:
Can the rotor be rotated manually		Any evidence of burnt component/s?	
Interior motor condition?		Exterior motor condition?	
Routine Test Before Stripping? **Yes / No**		Warrantee Repair Conditions Apply? **Yes / No**	
Recommended Scope of Work for improvements or repair:			
Required Delivery Date:	Repair Classification:	Urgent / Emergency	Normal

Components on motor that is ready for collection	Present YES	Present NO	Additional Information / Instruction:
Is the motor complete?			
Is the coupling fitted?			
Is there a Terminal Box on Line Side?			
Has the Line Side Terminal Box got its cover?			
Is the cable gland plate fitted?			Visible condition of components:
Does the motor have its cooling fan?			
Is there a fan cowl on the motor?			
Is there a Terminal Box on Neutral Side?			
Has the Neutral/Star Side Terminal Box got its cover?			

REPORTED BY:		SIGNATURE:	
SUPERVISOR:		SIGNATURE:	

On day of motor collection

DATE LOADED:		REPAIR COMPANY:	
LOADED BY:		SIGNATURE:	
DEL. NOTE:		GATE RELEASE:	

APPENDIX E: TEST EQUIPMENT SPECIFICATIONS

TEST	TEST EQUIPMENT REQUIREMENTS
Tan-δ Test	An appropriate size 50 Hz AC test unit to provide the required measurements at applied voltage from 20% to 100%, at 20% increments, of motor rated line-to-line voltage shall be utilised. The accuracy of the bridge shall be, at worst, 1%.
Stator Coil Tests	The impulse generator used shall be capable of generating impulses with peak values in excess of 50 kV and front rise times of 0.1 to 0.2 μs. The test voltage and wave shape of the impulse wave shall be subject to the *Employer's* approval.
Winding Insulation Resistance Tests	Insulation Resistance (IR) tests shall be conducted with a capable megohm meter to determine equipment which will on output provide a plotted trend of the measured insulation resistance as a function of time throughout the entire duration of the measurement of the IR_{1min} and IR_{10min}. The plot must be from readings measured every 5-seconds. From the trend the Dielectric Absorption Ration (DAR) and Polarization Index (PI) will be calculated by measuring and recording the 30-second reading (IR_{30sec}), 1-minute reading (IR_{1min}), and 10-minute reading (IR_{10min}). The DC megohm meter shall be capable of developing and displaying test voltages.
Stator Winding Resistance Test	A bridge-type instrument or digital ohmmeter capable of measuring and displaying milliohms shall be used to record the three line terminal-to-terminal stator winding DC resistance values, i.e., R_{UV}, R_{VW} and R_{WU}. Letters U-V-W may be substituted by A-B-C, depending on the terminal notation.
No-load Test	As per section 4.4.5.3 and as per *Eskom 240-50237155*.

Test Power Supply and Instrumentation Quality	The test facility shall have the power supply source and instrumentation that is capable of meeting the following requirements throughout the test duration;
	
	a. The harmonic distortion coefficient, THD, shall not exceed 0.05.
	b. The voltage unbalance shall not exceed 0.5%.
	c. The frequency shall be within ±0.5% for routine test, and ±0.1% for performance test of motor rated frequency. The power supply frequency range is, therefore, limited to 49.75-to-50.25 Hz for routine test, and 49.95-to-50.05 Hz for performance test.
	d. Variations in frequency during a test shall not exceed 0.33% of the average frequency.
	e. Power supply quality shall be monitored, and automatically controlled throughout the test duration. The supply conditions shall be recorded throughout the tests, and such records must form part of the motor test record.
	f. The accuracy of instrumentation used to measure test data shall be in accordance with SANS IEC 60034-2-1 requirements.
	g. The capabilities of vibration measurement instruments shall include the following;
	• Can measure displacement, velocity, acceleration, and phase.
	• The software must be able to convert the vibration time waveform between acceleration and velocity.
	• Minimum zoom factor of 10 to enable high-resolution spectral analysis. The analyser shall therefore be able to permit time period (maximum frequency) settings of 12 000 CPM (200 Hz) for 1 600 lines of resolution by machine speed.
	• Log amplitude scale
	• Wide frequency response range of 0 Hz – 20 kHz, as a minimum, for standard vibration measurements. To reliably detect all calculable rolling element bearing defect frequencies, high-frequency vibration analysis instruments that have a frequency response range of 25 kHz – 36 kHz are required.
	• Plots that can be produced include;
	  o Time waveforms
	  o Plots of overall vibration amplitudes
	  o Vibration amplitudes in specific frequency bands
	  o Trend plots
	  o Bode plots
	  o Vibration spectrum and overall vibration in one measurement
	• Recording of run test data shall be computerised and automatically transferred from the measuring instrument onto the test report, without human interference.

Crane	The lifting Cranes shall be suitably rated, with excess lifting capacity for the size of motor to be lifted.
Vibration Measurements	For time waveform analysis, standard resolution measurements shall be taken on all directions with the vibration analyser set to 1600 lines of resolution and maximum frequency to at most 30 kCPM (500 Hz). The direction that exhibits the highest standard resolution vibration on either end shall have high resolution measurements taken with the analyser set to no less than 3200 lines of resolution and maximum frequency to at most 12 kCPM (200 Hz).

AC Hi Potential Test	Equipment which is capable of an output AC voltage of three times the rated Line-Line voltage of the motor under test. The high-voltage test procedure shall comply with IEC Standard 60034-1.
DC Hi Potential Test	The AC supply circuit utilising the stable system 50Hz source should be free from intermittent loads and transients. A test set with 0.1% line regulation or better high voltage output is required. The output current meter must be capable of selecting several current ranges for improved sensitivity to typically measured microamperes. Current measurements must be either voltage or time based. If the test set includes overcurrent trip, it should be calibrated for a setting high enough to avoid insulation-stressing inadvertent trips during the test.
Impulse Testing	As per Eskom Standard 240-50237155 all coils installed in the stator shall have inter-turn insulation surge/impulse tested in accordance with IEEE Std 522, while tests conducted on sample coils shall be conducted in accordance with SANS IEC 60034-15.
Performance Test	As per section 4.4.6 and as per *Eskom 240-50237155*.