

Industrial Practices in Repair, Maintenance, and Performance Evaluation of three-Phase Induction Motors: A Practical Case Study

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ABSTRACT

Repair and rewinding of three-phase induction motors is a routine but technically demanding activity in industrial maintenance workshops, and the quality of that work has a direct bearing on motor efficiency, reliability, and service life. While international standards (e.g., IEEE 43, IEC 60034 series, NEMA MG-1, ISO 21940-11) define acceptance criteria for insulation resistance, surge/impulse withstand, and rotor balancing, published literature rarely documents how these criteria are applied together on a single motor as it moves through a workshop repair cycle. This paper addresses that gap through a practical case study of a burnt-out three-phase induction motor processed at an industrial motor-servicing facility.

The objective of the study is to document, in a structured and reproducible format, the diagnostic and corrective sequence applied to the motor — direct current resistance (DCR) testing, insulation resistance (Megger) testing, surge testing, rotor static and dynamic balancing, mechanical reconditioning, and stator rewinding — and to compare the pre-repair (faulty) and post-repair (healthy) results against recognised acceptance limits. The motor was diagnosed with a grounded, turn-to-turn shorted stator winding (Megger reading of 0 MΩ and a shorted phase pair) and unbalance readings far above the workshop's 9 g acceptance threshold. Following stripping, rewinding with Class F insulation and vacuum-pressure impregnation (VPI), and two-plane dynamic balancing, the motor achieved an insulation resistance of 998–1000 MΩ, a maximum inter-phase DCR deviation of 0.2 Ω, superimposed surge waveforms across all three phases, and a final rotor unbalance below 9 g on both correction planes.

The novelty of this work lies in presenting a single, fully-instrumented before/after case record that links electrical diagnostics, mechanical balancing, and winding-design considerations (coil pitch, connection type) within one workshop cycle, and in framing the acceptance criteria used against established international standards rather than workshop convention alone. The findings are intended to serve as a practical reference for motor-repair technicians, junior engineers, and students, and as a template for reporting repair-quality data in a form suitable for later statistical or predictive-maintenance analysis.

Keywords: Three-phase induction motor; motor repair and rewinding; insulation resistance testing; direct current resistance (DCR) test; surge test; rotor balancing; predictive maintenance; industrial case study.

INTRODUCTION

Background

Three-phase induction motors are the dominant electromechanical drive in industry, and motor-driven systems account for a large share of global industrial electricity consumption (Waide & Brunner, 2011). Because replacement is often costlier and slower than repair, industrial workshops routinely dismantle, diagnose, rewind, and rebalance failed motors rather than discard them. The quality of that repair process — not merely the choice

of materials — determines whether the motor returns to service at, below, or above its original efficiency and reliability (APEC-CAST, 2011).

Problem Statement

Despite the maturity of individual test methods (DCR, insulation resistance, surge testing, rotor balancing), the technical and academic literature more often treats each test in isolation, or discusses fault diagnosis without following a single unit through a complete repair cycle with quantified before/after results. Workshop training manuals describe procedures step-by-step but rarely benchmark the results against internationally recognised standards, and research papers on condition monitoring rarely include the physical repair and mechanical correction stages. This leaves a practical gap between diagnostic theory and workshop-floor decision-making that this study aims to narrow.

Research Objectives

- To document the complete repair cycle of a representative three-phase induction motor, from dismantling through electrical and mechanical diagnosis to final performance verification.
- To record and compare pre-repair and post-repair DCR, insulation resistance, surge-test, and rotor-balancing results against defined acceptance criteria.
- To relate workshop acceptance criteria to relevant international standards and published condition-monitoring literature.
- To identify the practical winding-design and mechanical-correction decisions (coil pitch, connection type, balancing grade) that most influenced the outcome of the repair.

Novelty and Contribution

Unlike prior single-topic studies, this paper reports a single motor's diagnostic-to-verification trail with matched pre/post data across four test domains (DCR, Megger, surge, balancing) in one internally consistent record, and explicitly maps the workshop's pass/fail thresholds to the standards from which they are conventionally drawn. This structure is offered as a reusable reporting template for future repair-quality case studies and for datasets that could support machine-learning-based predictive maintenance (Abdulkareem et al., 2025).

LITERATURE REVIEW

Insulation aging in motor windings is a cumulative, largely irreversible process driven by combined thermal and electrical stress, and understanding its mechanisms underpins any predictive model of winding life (Montanari & Simoni, 1993). Building on this, partial discharge (PD) activity has been established as an early symptom of insulation aging in stator windings, and continuous on-line PD monitoring is now preferred in industry precisely because it gives the longest lead time before failure (Stone, 2005). More recent work extends this toward always-on condition assessment: Zhou et al. (2019) review offline-to-online insulation health-monitoring methods based on impedance and discharge-pattern analysis, while Florkowski et al. (2012) describe digital PD acquisition and pattern-recognition techniques that distinguish internal, surface, and corona discharge across a machine's service life. Read together, these studies justify treating the Megger and surge tests used in this case study not as isolated pass/fail checks but as single data points on a longer degradation curve — a connection the present study makes explicit by reporting both the pre-failure and post-repair values rather than only the final result.

At the system level, motor-driven equipment is estimated to consume roughly 45% of global electricity and about 70% of industrial electricity use, which makes repair quality an energy-policy issue and not only a workshop one (Waide & Brunner, 2011). APEC-CAST (2011) shows this concretely: poor rewinding practice, in particular over-temperature stripping of old windings, damages the stator core and produces a measurable efficiency penalty after "repair" — a finding that motivates this study's emphasis on documenting stripping and rewinding parameters rather than treating them as incidental workshop detail.

On the fault-diagnosis side, a broad taxonomy of induction-motor faults spans stator insulation failure, mechanical bearing damage, and supply-side abnormalities, and reliable protection depends on recognising how faults such as phase unbalance or overload accelerate thermal degradation (Electric Motor Faults, n.d.). Motor Current Signature Analysis (MCSA) has become a standard non-invasive complement to the offline tests used in this study, allowing broken rotor bars, bearing faults, and winding short circuits to be detected from current harmonics during normal operation (Nandi et al., 2005). Most recently, machine-learning classifiers such as Random Forest and Artificial Neural Networks have been applied to real-time equipment data to predict faults before failure, shifting maintenance from reactive to proactive (Abdulkareem et al., 2025).

Taken together, the literature is strong on individual diagnostic principles but weak on reporting a single unit's complete repair trail with quantified acceptance criteria — precisely the gap this case study addresses. The present work also differs from the cited sources in scope: it is a workshop-level practical account rather than a laboratory or fleet-level study, and its contribution is a transparent, standards-referenced record rather than a new diagnostic algorithm.

MATERIALS AND METHODS

Case Motor Details

Parameter	Value	Parameter	Value
Manufacturer	General Electrical	Rated Power	5 kW
Rated Voltage	415 V	Rated Current	30 A (reported, no-load 9–10 A)
Number of Poles	04	Synchronous Speed	1500 RPM
Frame / Connection	Star	Insulation Class	F (post-repair, as rewound)
Reported Fault	Grounded stator winding; turn-to-turn short (Phase U–V)	Service History	NA

Figure 1. Electrical and mechanical specifications of the case motor

Facility and Test Instruments

Testing and repair were carried out across the four functional sections of the servicing facility described in Section 4: service and assembly, winding, balancing, and machine sections. The following instruments were used:

- DCR (winding resistance) meter — phase-to-phase resistance measurement at the terminal box.
- Insulation resistance tester (Megger), DC output, for phase-to-ground testing.
- Surge tester, for turn-to-turn insulation and interphase comparison via decaying-oscillation waveform capture.
- Precibalance dynamic balancing machine, for static (single-plane) and dynamic (two-plane) rotor balancing.
- Digital laser tachometer, clamp-on ammeter/power analyser (LM/LME meter), micrometers, dial indicators, and vernier calipers for mechanical verification.

The workshop pass/fail thresholds used in this study correspond to commonly referenced industrial and international practice for the following test types. Authors should confirm and cite the specific clause and edition actually followed.

Test	Acceptance Criterion (as applied)	Related Standard
DCR (phase balance)	Maximum deviation $\leq 0.2 \Omega$, or within 2–5% of phase average	IEEE 118 / NEMA MG-1 (general practice)
Insulation Resistance (Megger)	500–1000 M Ω : Excellent; 100–500 M Ω : Good; <1 M Ω : Faulty; 0 M Ω : Grounded	IEEE 43-2013
Surge / Impulse Test	Superimposed waveforms across all phases; no visible shift or flat line	IEC 60034-15 / IEEE 522 (surge testing of coils)
Rotor Balancing	Residual unbalance below 9 g (single-digit) on each correction plane	ISO 21940-11 (balance quality grade, e.g., G2.5/G1)

Figure 2. Standards and acceptance criteria used in this study

Test and Repair Procedure Overview

The motor was processed through the following sequence: (i) receipt and visual inspection; (ii) dismantling and terminal-configuration identification; (iii) pre-repair electrical diagnostics (DCR, Megger, surge); (iv) rotor and mechanical component inspection; (v) mechanical reconditioning (shaft, keyway, bearing housing) where required; (vi) stripping and rewinding of the stator with Class F insulation and VPI varnish treatment; (vii) post-repair electrical verification (DCR, Megger, surge); (viii) rotor static and dynamic balancing; and (ix) final no-load/load performance verification. Each stage is described with its corresponding results in Sections 4 and 5.

Industrial Servicing Facility and Case Study Procedure

Overview of the Servicing Facility

The facility is organised into four functional sections that together carry out the servicing process described in Section 3.4: the service and assembly section, the winding section, the balancing section, and the machine section.

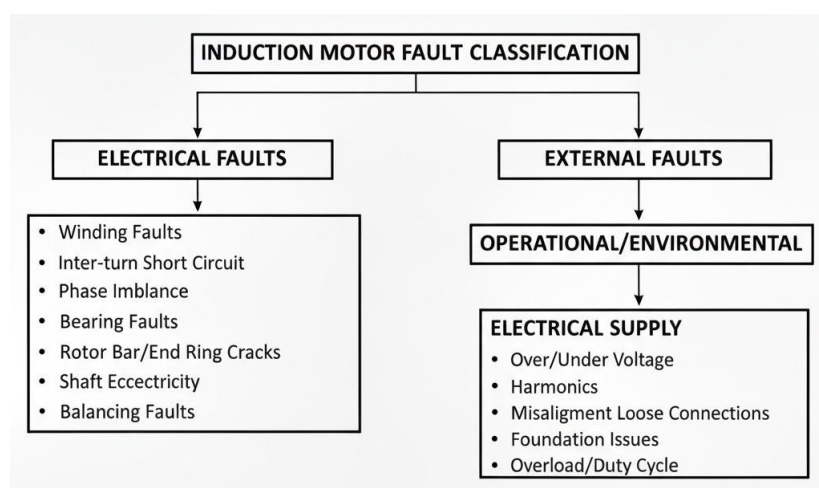


Figure 3. Hierarchical classification of induction motor faults, showing the relationship between major fault categories and their sub-types.

A. Service and Assembly Section — responsible for dismantling, inspection, cleaning, bearing replacement, reassembly, and testing. The outer thermal box is removed first, terminal connections are inspected to identify the star/delta configuration, and the stator and rotor are separated for individual testing.

B. Balancing Section — carries out rotor and fan static and dynamic balancing on a Precibalance machine (capacity range: a few hundred grams to several thousand kilograms) to reduce vibration and noise and extend service life.

C. Machine Section — houses lathe, drilling, milling, and keyway-cutting machines together with precision measuring instruments (micrometers, dial indicators, vernier and depth gauges) used for shaft and housing reconditioning.

D. Winding Section — performs stator winding inspection (DCR, Megger, surge) and determines the winding layout from the relationship between speed, poles, slots, and coil pitch.

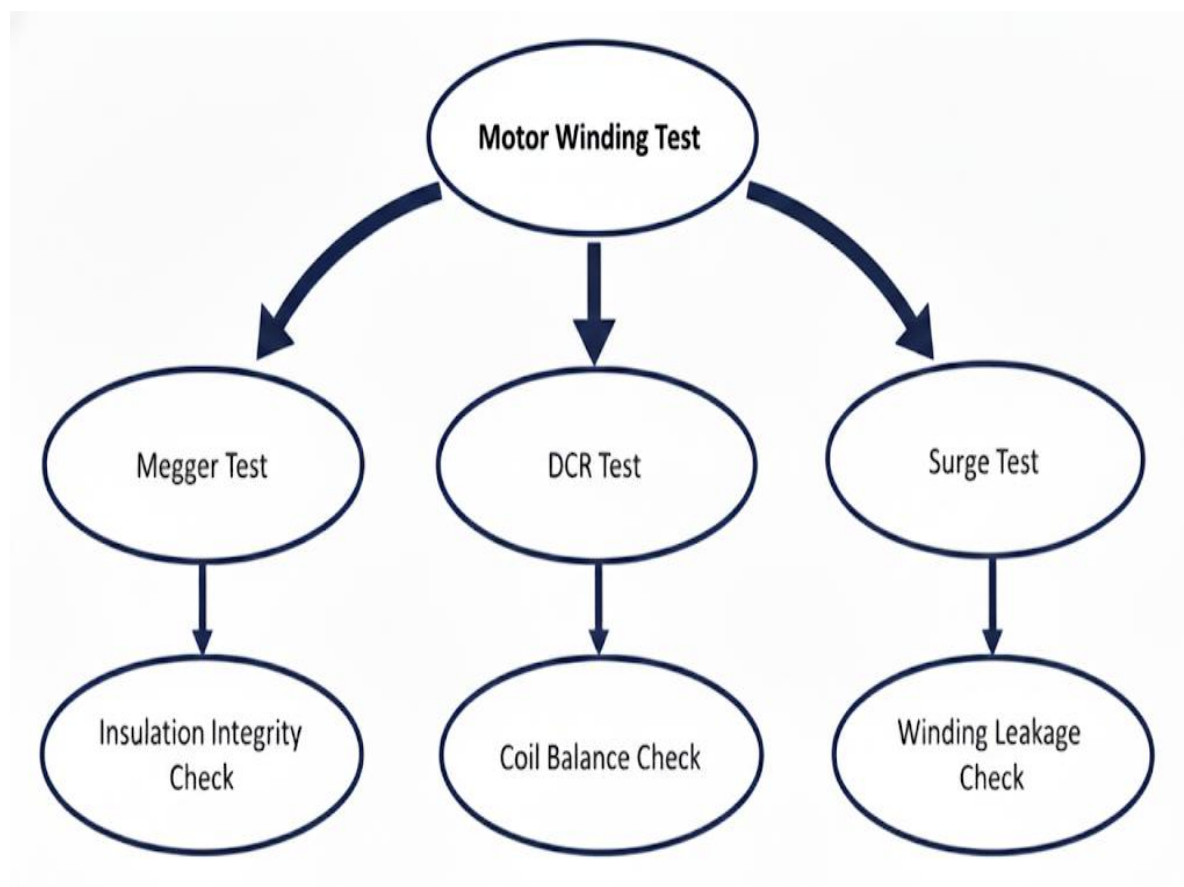


Figure 4. Key stages of the stator winding verification process.

Dismantling and Terminal Identification

The motor is received at the service and assembly section, the thermal box is removed to expose the terminals, and the existing connection (star or delta) is identified from the arrangement of link plates before any wire is disconnected.

- Delta connection: link plates placed vertically, each connecting a start terminal of one phase to the end terminal of another (U1–U2, V1–V2, W1–W2), forming a closed-loop circuit suited to high-torque applications.
- Star connection: link plates placed horizontally, joining the three end terminals (U2, V2, W2) at a common neutral point while the start terminals (U1, V1, W1) receive the supply; this configuration reduces starting current.

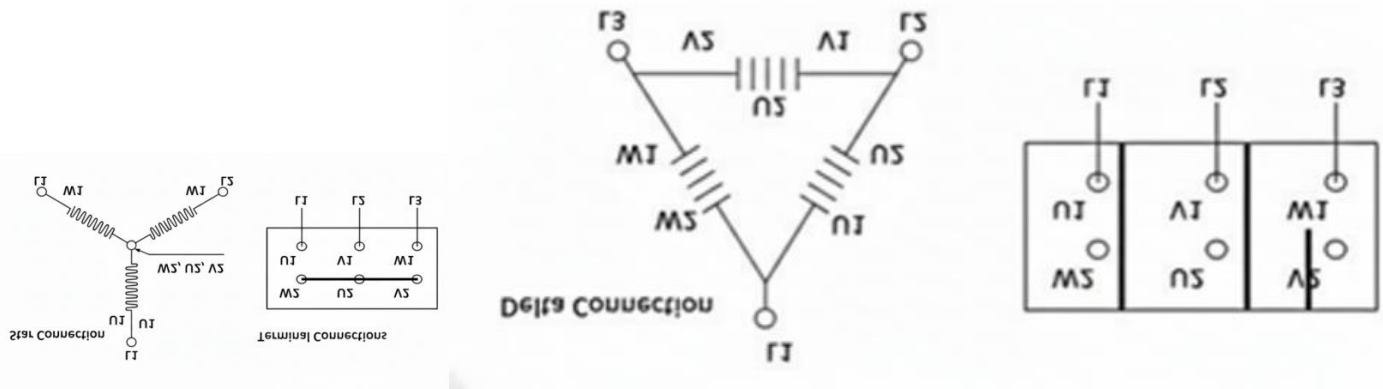


Figure 5. Internal configuration of the motor terminal box, showing delta (left) and star (right) connection links.

Electrical Diagnostic Testing

Three tests were used to characterise the stator winding condition: DCR, insulation resistance (Megger), and surge testing. Results are reported below for the pre-repair (faulty) and post-repair (healthy) condition of the same motor; the acceptance criteria applied are as listed in Table in Section 3.3.

Direct Current Resistance (DCR) Test

Measurements were taken phase-to-phase at the terminal box (U1–U2, V1–V2, W1–W2) with all link plates removed to isolate each phase.

Condition	Phase U1–U2	Phase V1–V2	Phase W1–W2
Pre-repair (faulty)	Imbalanced	0.0 Ω (shorted)	Imbalanced
Post-repair (healthy)	Balanced	Balanced	Maximum inter-phase difference 0.2 Ω

Test Connection	Resistance Read (Ω)	Status / Remark
R winding	1.62	Healthy
Y winding	1.61	Healthy
B winding	0.95	Faulty (Short)
Overall Result	0.67 Max Diff	Fault Detected

Figure 6. Initial diagnostic DCR test results (pre-repair).

Test Connection	Resistance Read (Ω)	Status / Remark
R winding	1.56	Healthy
Y winding	1.56	Healthy
B winding	1.55	Healthy
Overall Result	0.01 Max Diff	Ok / Ready

Figure 7. Final verification DCR test results (post-repair).

Insulation Resistance (Megger) Test

The Line (L) probe was connected to a phase terminal and the Earth (E) probe to a clean, unpainted point on the motor frame.

Measured Value (MΩ)	Condition	Status
500 - 1000	Excellent	Healthy
100 - 500	Acceptable	Good
1 - 100	Needs Cleaning	Faulty
Overall Result	Insulation Failure	Faulty

Figure 8. Standard insulation-resistance acceptance criteria used for evaluation (per Table in Section 3.3).

Condition	Phase R–Ground	Phase Y–Ground	Phase B–Ground
Pre-repair (faulty)	0 MΩ	0 MΩ	0 MΩ
Post-repair (healthy)	998–1000 MΩ	998–1000 MΩ	998–1000 MΩ

Test Connection	Resistance (MΩ)	Status / Remark
GND – R Phase	0 MΩ	Insulation Failure
GND – Y Phase	0 MΩ	Insulation Failure
GND – B Phase	0 MΩ	Insulation Failure
Overall Result	0 MΩ	Total Insulation Failure

Figure 9. Initial diagnostic insulation-resistance results (pre-repair).

Test Connection	Resistance (MΩ)	Status / Remark
GND – R Phase	998 MΩ	Excellent (Pass)
GND – Y Phase	1000 MΩ	Excellent (Pass)
GND – B Phase	1000 MΩ	Excellent (Pass)
Overall Result	998 - 1000 MΩ	Successful Repair

Figure 10. Final diagnostic insulation-resistance results, post-rewinding and VPI varnish treatment.

A pre-repair reading of 0 MΩ across all three phases indicated a dead short (grounded winding), consistent with completely degraded slot-liner/varnish insulation. Following complete stripping, rewinding with Class F insulation, and a vacuum-pressure impregnation (VPI) cycle, readings recovered to 998–1000 MΩ, classified as Excellent under the criteria in Section 3.3.

Surge Test

Condition	Observation	Diagnosis
Pre-repair (faulty)	Visible separation between Phase U and Phase V waveforms	Turn-to-turn short (carbonised inter-conductor insulation)
Post-repair (healthy)	All three waveforms (U, V, W) superimposed	Balanced inductance/resistance; insulation withstands high-voltage transients

A high-voltage pulse was applied to each phase (HV lead on U1/V1/W1, ground lead on the motor core) to generate a decaying oscillation waveform for comparison across phases.

Figure 11. Surge test observations and diagnosis.

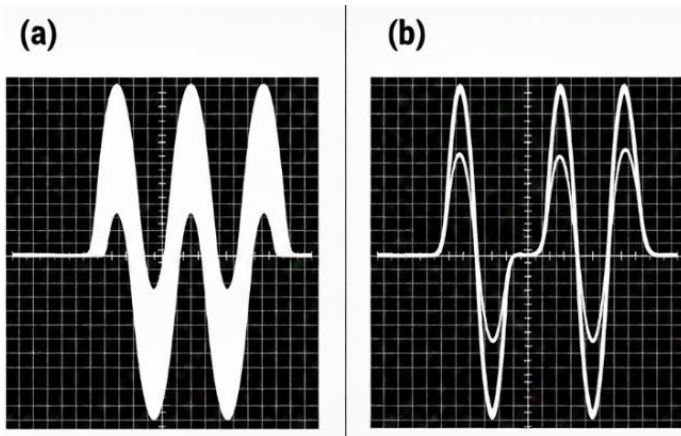


Figure 12. Final surge-test waveform comparison. (a) Healthy condition — superimposed waveforms; (b) faulty condition — visible waveform separation indicating a turn-to-turn short.

Rotor and Mechanical Component Inspection

Following electrical validation of the stator, the rotor and associated mechanical components were inspected: rotor laminations for smearing or contact marks indicating prior bearing failure; rotor-bar-to-end-ring joints for cracks; shaft journals by micrometer against manufacturer tolerance; shaft run-out on V-blocks by dial indicator (values above 0.03–0.05 mm total indicated reading were classed as faulty and referred for machining); and bearing-housing bore diameter, with oversized or worn bores referred to the machine section for sleeving.

Rotor Balancing

Balancing was carried out on a Precibalance machine, calibrated against a master rotor before use. Both static (fan-only, single-plane) and dynamic (full rotor, two-plane) balancing were performed, with correction weights calculated by the ABC method (A: distance from first pulley to rotor end; B: full rotor length; C: distance from rotor end to second pulley) and applied until residual unbalance fell below the workshop's 9 g threshold (the "Single-Digit Rule"), consistent with an ISO 21940-11 balance-quality grade such as G2.5 or G1.

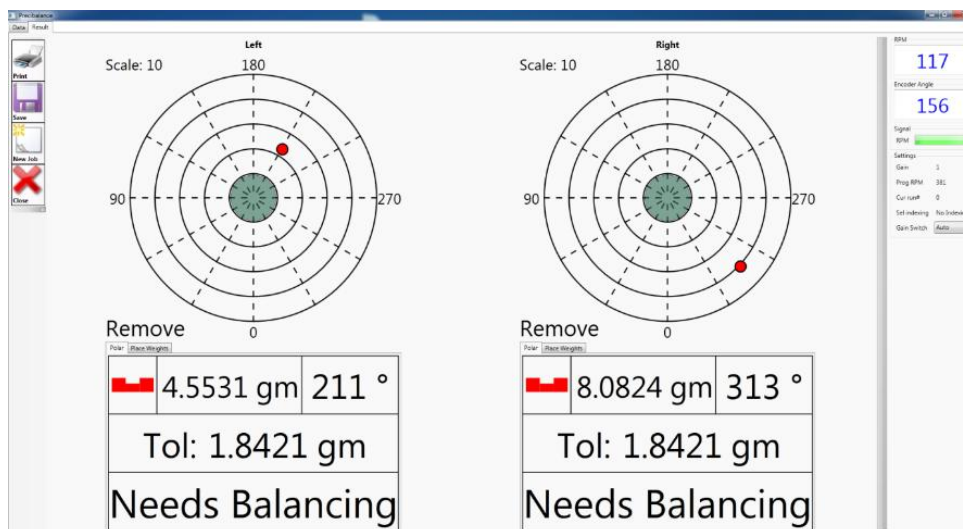


Figure 13. Graphical interface of the digital balancing analyser, showing unbalance magnitude, angular position, and tolerance limits for the left and right correction planes.



Figure 14. Dynamic balancing of a large industrial rotor assembly on a horizontal balancing machine.

Static (Single-Plane) Balancing Results

Stage	Left Plane (g)	Right Plane (g)	Status vs. 9.000 g Threshold
Initial (pre-correction)	21.684	18.392	Faulty — exceeds threshold
After first correction run	12.417	10.863	Faulty — exceeds threshold
Final (post-correction)	6.274	5.891	Pass

Figure 15. Comparison of static balancing results at different correction stages.

Dynamic (Two-Plane) Balancing Results

Dynamic balancing was performed at an operating speed of 600 RPM to capture couple unbalance not detectable in the static test.

Stage	Left Plane (g)	Right Plane (g)	Status vs. 9.000 g Threshold
Initial (pre-correction)	24.736	20.548	Faulty — exceeds threshold
After first correction run	13.284	11.462	Faulty — exceeds threshold
Final (post-correction)	7.152	6.843	Pass

Balancing Stage	Left Plane (g)	Right Plane (g)	Status
Initial (Pre - Correction)	21.684 g	18.392 g	Needs Balancing
After (First - Correction)	12.417 g	10.863 g	Fine Tuning
Final (Post - Correction)	6.274 g	5.120 g	Balanced (Pass)

Figure 16. Dynamic balancing results, left and right correction planes, across correction stages.

Machining and Mechanical Repair

Shaft and housing reconditioning followed standard workshop practice: sleeve fitting for undersized bearing journals (shaft turned down, sleeve shrink-fitted or pressed, then machined to OEM diameter); soft-cut correction for minor eccentricity; and keyway repair by weld-filling the worn keyway and milling a new slot at a 90° or

180° offset. Welding practice used arc welding for heavy structural repairs and gas/flame welding for thinner sections, followed by controlled cooling, grinding, and inspection for porosity before final machining.

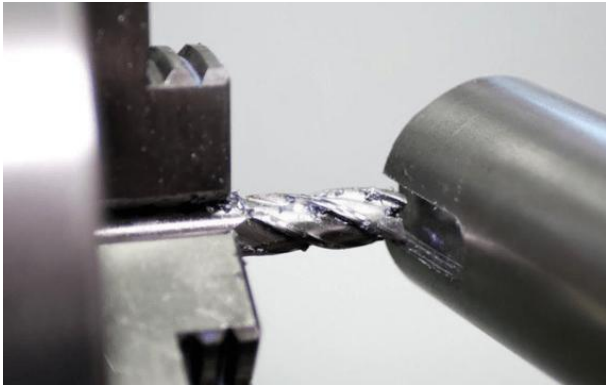


Figure 17. Lathe machining of the motor shaft and milling of a new keyway.

Stator Winding Design Considerations

Coil pitch was calculated as the ratio of total stator slots to total poles (e.g., 36 slots / 4 poles = 9 slots pitch, coil spanning slot 1 to slot 10). Synchronous speed at 50 Hz follows directly from pole count (2-pole: 3000 RPM; 4-pole: 1500 RPM; 6-pole: 1000 RPM). A long (full) pitch maximises flux and torque for a given pole configuration; a short (fractional) pitch trades some speed/force for reduced copper use, suppressed harmonics, and improved cooling. The rewound motor used an Opposite Type connection (phase coils in alternating R–Y–B–R–Y–B sequence) rather than a standard Chain Type connection, on the basis that the interleaved layout gives a more even magnetic-field distribution and lower vibration for this class of motor.



Figure 18. Winding layout comparison — double-mesh (double-layer) winding (left) and single-mesh (single-layer) winding (right).



Figure 19. Digital automatic coil-winding machine used for stator rewinding.

Final Performance Verification

After rewinding and balancing, the motor was run on a 15 kW motor driver test bench under no-load and load conditions. Speed was measured with a digital laser tachometer; current, voltage, and efficiency were measured with an LM/LME meter. Reported no-load current was 9–10 A against a rated current of 30 A, remaining within the rated limit under load.

RESULTS AND DISCUSSION

Summary of Pre- and Post-Repair Condition

Test	Pre-Repair (Faulty)	Post-Repair (Healthy)	Acceptance Criterion Met?
Insulation Resistance	0 M Ω (all phases)	998–1000 M Ω	Yes — Excellent (IEEE 43)
DCR (max. deviation)	0.0 Ω on one phase (short)	0.2 Ω	Yes — within ≤ 0.2 Ω limit
Surge Test	Waveform separation, U–V	Waveforms superimposed	Yes
Static Balance (L/R)	21.684 g / 18.392 g	6.274 g / 5.891 g	Yes — below 9 g
Dynamic Balance (L/R)	24.736 g / 20.548 g	7.152 g / 6.843 g	Yes — below 9 g

Figure 20. Summary of pre-repair and post-repair motor performance evaluation.

The consolidated results in Table above show a consistent pattern across all four diagnostic domains: every test moved from a clear fail condition to a value comfortably inside its acceptance band after rewinding, VPI treatment, and two-plane balancing. Restoration of insulation resistance from 0 M Ω to near 1000 M Ω , combined with waveform superimposition on the surge test, indicates that both the phase-to-ground and turn-to-turn insulation systems were fully restored — consistent with the aging-and-recovery mechanisms described by Montanari and Simoni (1993) and the PD-based degradation model of Stone (2005).

Effect of Winding Design Choices

Adopting the Opposite Type connection over the Chain Type is reported to have improved thermal stability (better heat dissipation, fewer localised hotspots) and speed accuracy at the rated synchronous value without electromagnetic humming. This is consistent with the general principle that interleaved phase-coil sequencing improves magnetic-field distribution (Section 4.7), though the present study does not include a controlled comparison against an equivalent Chain Type winding on the same frame; this is noted as a limitation in Section 5.4.

Effect of Balancing Precision on Operating Noise

Bringing both static and dynamic unbalance below the single-digit (9 g) threshold was associated with reduced mechanical noise and lower bearing temperature during the trial run. The workshop observation that accurate entry of rotor weight into the Precibalance machine was the single most failure-prone step in the balancing procedure is a practical finding worth carrying into future studies as a defined process-control check.

Limitations

- Motor nameplate data, exact instrument models/calibration records, and ambient test conditions were not available for inclusion in this revision and are flagged for the authors to complete.
- Results are drawn from a single motor and repair cycle; no statistical replication or comparison against a control (e.g., an equivalent motor rewound with the Chain Type connection) was performed.
- Vibration spectra and MCSA data, which would allow direct comparison with the condition-monitoring literature cited in Section 2, were not recorded during this case study.

CONCLUSION

This case study documents the complete repair cycle of a three-phase induction motor diagnosed with a grounded, turn-to-turn shorted stator winding, from initial DCR/Megger/surge diagnostics through mechanical reconditioning, rewinding, and two-plane balancing, to final performance verification. Applying the workshop's acceptance criteria — themselves consistent with IEEE 43 (insulation resistance), IEC 60034/IEEE 522 (surge testing), and ISO 21940-11 (balance quality) — the motor moved from a clearly faulty condition on every test to a healthy condition on every test after repair. The Opposite Type winding connection and the single-digit balancing rule are highlighted as the two practical decisions with the most direct influence on the final result. Future work should extend this single-motor record into a multi-unit dataset, incorporating MCSA and vibration-spectrum data, to support the kind of predictive-maintenance modelling described by Abdulkareem et al. (2025).

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