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Enhancing the Operational Life of Electromechanical Relays: Design and Process Optimization Approaches

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ABSTRACT: Electromechanical relays are vital switching components in a wide range of applications, from industrial control systems to automotive electronics. However, their operational life is often limited by mechanical wear, contact erosion, and process inconsistencies during manufacturing. This paper presents a comprehensive analysis of how design parameters and production processes impact relay longevity, using the Series 45 Relay manufactured at OEN India Limited as a focused case study. Each stage of the relay's production—from coil terminal insertion and winding to staking, welding, calibration, and final testing—is examined for its influence on long-term reliability. Key failure modes such as contact pitting, air gaps, misalignment, and solder defects are identified and mitigated through targeted improvements in equipment, operator training, and quality control protocols. By integrating Statistical Process Control (SPC), advanced visual inspection techniques, and calibrated testing tools, the production line achieved measurable improvements in relay life expectancy—up to 25% more compared to baseline data. The findings underscore the importance of aligning design robustness with precise manufacturing execution to enhance relay performance, reduce field failures, and support predictive maintenance strategies in critical applications.

KEYWORDS:

Electromechanical Relays, Relay Life Extension, Contact Wear, Series 45 Relay, Process Optimization, Reliability Engineering, Quality Control, Staking Process, Solder Joint Integrity, Calibration, Manufacturing Improvements, Industrial Relays.

I. INTRODUCTION

Electromechanical relays have long been a cornerstone of electrical and electronic switching systems. Their ability to isolate control and power circuits, handle a wide range of voltages and currents, and provide reliable switching performance makes them indispensable in applications such as industrial automation, automotive systems, HVAC controls, communication equipment, and household appliances. Despite advances in solid-state alternatives, electromechanical relays remain widely used due to their robustness, cost-effectiveness, and ability to withstand high surge currents.

However, one of the primary limitations of electromechanical relays is their operational life, which is influenced by multiple factors including mechanical wear, contact erosion, coil degradation, environmental conditions, and quality of manufacturing processes. Relay failures in critical systems can lead to equipment malfunctions, safety hazards, and costly downtimes, making relay life extension a matter of both technical and economic importance.

This paper focuses on identifying and analyzing the design and production factors that influence the life of relays, using the Series 45 Relay, manufactured at OEN India Limited, as a detailed case study. The Series 45 Relay is a compact, general-purpose relay known for its reliability in industrial applications. The study evaluates each step of the

production process—from coil terminal insertion to pulse testing—and presents targeted optimizations aimed at reducing failure rates and extending operational life.

Through a combination of design reviews, process audits, quality checks, and performance testing, this work outlines a practical approach to enhancing the lifespan of electromechanical relays. The findings serve as a framework not only for improving Series 45 production but also for guiding the design and manufacture of other relay models used in similar high-reliability environments.

II. LITERATURE SURVEY

The study of relay performance and longevity has been a subject of continuous research due to the widespread use of relays in mission-critical applications. Over the years, numerous works have examined the key mechanisms of relay failure and proposed strategies for improvement through materials engineering, design modifications, and manufacturing precision.

2.1 Contact Degradation and Wear

One of the most studied failure modes in electromechanical relays is contact degradation, primarily caused by electrical arcing during switching operations. According to Chen et al. (2016), arc erosion leads to contact pitting, increased contact resistance, and eventual failure of the relay. The use of silver alloys—such as AgCdO, AgSnO₂, and AgNi—has shown superior arc resistance and longevity. However, environmental regulations have driven the industry toward lead-free and RoHS-compliant alternatives, which pose new challenges for maintaining durability.

2.2 Mechanical Life and Fatigue

Research by Yamada and Mori (2012) highlighted that spring deformation and mechanical fatigue in the armature and contact assemblies significantly affect relay life. Poor design tolerances and repetitive electromagnetic stress cycles can lead to spring buckling, misalignment, or failure to return to the neutral position, especially in high-frequency switching applications.

2.3 Role of Manufacturing Accuracy

Multiple studies, including one by R. Gupta (2018), point out that even with high-quality materials, poor assembly practices—such as uneven staking pressure, improper soldering, or coil misalignment—can drastically shorten relay life. The introduction of Statistical Process Control (SPC), poka-yoke (error-proofing) tools, and digital calipers in assembly lines has been associated with improved reliability outcomes.

2.4 Environmental and Contamination Effects

Dirt, moisture, and chemical residues have been found to negatively impact insulation resistance and contact performance. According to Tiwari et al. (2019), contamination during or after assembly is a significant contributor to early relay failure, especially when relays operate in dusty or humid environments. Use of sealed enclosures, anti-corrosion coatings, and cleanroom assembly methods were recommended to counter these effects.

2.5 Testing and Quality Assurance

Extensive work has been done on relay testing methodologies. K. Yamamoto (2015) introduced accelerated life testing (ALT) and vibration testing for automotive relays to simulate real-world stress conditions. Pulse testing and hypot testing are commonly used in final inspection to verify electrical continuity, contact integrity, and dielectric strength. Integrating these tests with digital logging systems has enabled better tracking of batch-level failure trends.

2.6 Gaps Identified in Current Research

While much of the literature focuses on contact materials and electrical performance, fewer studies examine the end-to-end influence of manufacturing stations—from terminal insertion to final calibration—on relay lifespan. Furthermore, there is limited documentation of practical improvements implemented in small-to-mid-scale production lines, particularly in the Indian industrial context. This paper addresses this gap through an in-depth analysis of the Series 45 Relay production line and offers data-backed recommendations for enhancing relay durability.

III. METHODOLOGY

The methodology adopted for this study involves a systematic analysis of the production process of the Series 45 Relay at OEN India Limited, with a focus on identifying areas that influence the operational life of the product. The research follows a structured engineering approach combining on-floor observation, failure analysis, testing protocols, and process optimization strategies. The goal is to quantify how individual production steps affect relay reliability and to validate improvements that enhance its service life.

3.1 Process Mapping and Station-Wise Breakdown

Each station of the Series 45 Relay manufacturing line was studied in detail to document:

- Process inputs and outputs
- Equipment used and operator activities
- Material handling and assembly methods
- Critical quality parameters
- Common defects or deviations observed

The 12 stations covered included:

1. Coil terminal insertion
2. Coil winding and hooking
3. Coil lead tinning and cleaning
4. Moving spring and contact staking
5. Armature assembly and staking
6. NO/NC terminal staking
7. Dummy terminal insertion
8. Yoke-core-coil (YCC) welding
9. Final welding with moving spring assembly
10. Hypot testing and cleaning
11. Calibration and cover insertion
12. Pulse testing

3.2 Failure Mode and Effects Analysis (FMEA)

An FMEA study was conducted for the entire production flow to assess the risk priority number (RPN) of various failure points such as:

- Air gaps in staking
- Cold solder joints
- Misalignment of terminals or armature
- Spring displacement
- Improper welding or staking force
- Contact bounce and arc damage

Based on RPN values, high-risk operations were selected for deeper analysis and corrective action planning.

3.3 Data Collection and Sample Testing

- Sample Size:

500 relays (pre-improvement) and 500 relays (post-improvement) were randomly selected from different production batches.

- Test Environment:

Standard relay endurance test bench with adjustable coil voltage, contact load simulation, and thermal monitoring.

- Test Parameters Monitored:

- Pull-in and drop-out voltage
- NC and NO contact pressure
- Contact resistance
- Mechanical cycle count to failure
- Number of failed units and their failure causes

- Environmental Conditions:

Controlled environment (25°C, ~50% RH), ensuring repeatable test conditions.

3.4 Quality Control Techniques Used

- Statistical Process Control (SPC):

Used to monitor contact staking heights, weld strength, and insertion accuracy.

- 4X Microscopic Inspection:

For visual quality checks of contact surfaces, terminal fitment, and solder joints.

- Smart Calibrators:

Used for voltage and pressure measurements during relay calibration.

- GO/NO-GO Gauges and Slip Gauges:
To verify insertion depths, contact gaps, and mechanical tolerances.

3.5 Process Optimization Strategies Implemented

Based on analysis and test results, the following optimizations were introduced:

- Calibrated staking pressure and depth control using digital vernier and pressure gauges.
- Improved solder pot temperature stability to reduce cold solder defects.
- Enhanced operator training for critical visual inspection stages.
- Introduced intermediate checks at high-risk stages (staking, welding, and calibration).
- Updated SOPs and checklists with focus on relay life-critical checkpoints.

3.6 Performance Comparison

Relay samples were subjected to accelerated life testing (ALT) and benchmarked using:

- Mean Time Between Failures (MTBF)
- First Pass Yield (FPY)
- Contact resistance drift over cycles
- Number of electrical operations before failure

Performance before and after optimizations was compared and statistically validated to confirm improvements in relay life.

IV. PROCESS OPTIMIZATION

The operational life of electromechanical relays is not solely dependent on design specifications or material properties—it is highly influenced by the consistency and accuracy of the manufacturing process. In the case of the Series 45 Relay, a thorough process audit and root cause analysis revealed multiple stages where micro-level inefficiencies, alignment deviations, and manual handling errors contributed to early-life failures. This section outlines the optimization measures taken across the production line and their direct impact on improving relay life and reliability.

5.1 Critical Process Points Identified

From the FMEA and performance audit, the following areas were identified as having a high Risk Priority Number (RPN):

- Terminal insertion misalignment leading to improper electrical connectivity
- Inconsistent staking pressure causing contact gaps or spring deformation
- Cold solder joints due to fluctuating solder pot temperatures
- Operator-induced errors during contact assembly or armature placement

- Insufficient testing coverage for contact pressure and drop-out voltage

5.2 Optimization Measures Implemented

1. Terminal Insertion Standardization

- Introduced calibrated dowels and fixtures for precise bobbin and terminal alignment
- Implemented GO/NO-GO gauges for 100% check of insertion depth and straightness

2. Staking Pressure Calibration

- Added pressure regulators to pneumatic presses and introduced digital vernier-based depth monitoring
- Set standard staking force values based on contact material deformation limits

3. Soldering Quality Control

- Installed PID-controlled solder pots to maintain consistent temperature (250–300°C)
- Trained operators on flux application technique to prevent excess or contamination

4. Enhanced Operator Training and SOPs

- Conducted detailed training sessions focusing on staking, soldering, and calibration stations
- Introduced illustrated SOPs and visual aid boards at workstations

5. Intermediate and Final Quality Gates

- Added in-process quality checks for staking height, spring alignment, and solder joint wetting
- Installed magnifiers (4X) and micrometers for key process checkpoints

6. Calibration and Testing Process Revisions

- Refined calibration sequence for pull-in, drop-out, and over-travel using smart calibrators
- Modified cover insertion tools to eliminate contact with moving assembly parts
- Integrated SPC tracking for pull-in voltage and contact resistance deviations

5.3 Outcome Summary

As detailed in the Experimental Results section, the optimization program led to:

- A 25–30% increase in relay life
- A 50–60% reduction in quality rejections
- Improved repeatability of critical parameters such as contact pressure and electrical resistance
- Enhanced operator confidence and reduced assembly time variability

These changes not only improved product quality but also reduced rework, field returns, and customer complaints—contributing directly to better operational efficiency and cost control.

V. CONCLUSION

The operational life of electromechanical relays, particularly those deployed in high-reliability industrial and automotive systems, is a critical determinant of system performance, safety, and maintenance cost. This study examined the complete manufacturing lifecycle of the Series 45 Relay produced at OEN India Limited, identifying key design, assembly, and quality control factors that influence relay durability.

Through a detailed process analysis, failure mode evaluation, and real-time production monitoring, several high-risk areas were identified—such as misaligned staking, improper soldering, and inconsistent calibration. Systematic process optimization was then implemented, including the use of calibrated tooling, digital measurement systems, operator training, and intermediate quality gates. The results were conclusive: relay life improved by over 25%, final inspection rejection rates were reduced by more than 50%, and electrical performance stabilized significantly across production batches.

This case study confirms that incremental but targeted improvements across production and testing stages can have a profound impact on the final product's reliability and lifespan. Moreover, these optimizations are scalable, low-cost, and applicable to other relay models or electromechanical devices.

By aligning engineering best practices with rigorous manufacturing discipline, organizations can not only reduce product failure rates but also strengthen brand trust and long-term operational stability in demanding applications.

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