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IMPACT OF CRIMPING CROSS - SECTION ANALYSIS EQUIPMENT IMPLEMENTATION ON PROCESS EFFICIENCY

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CHAPTER I INTRODUCTION

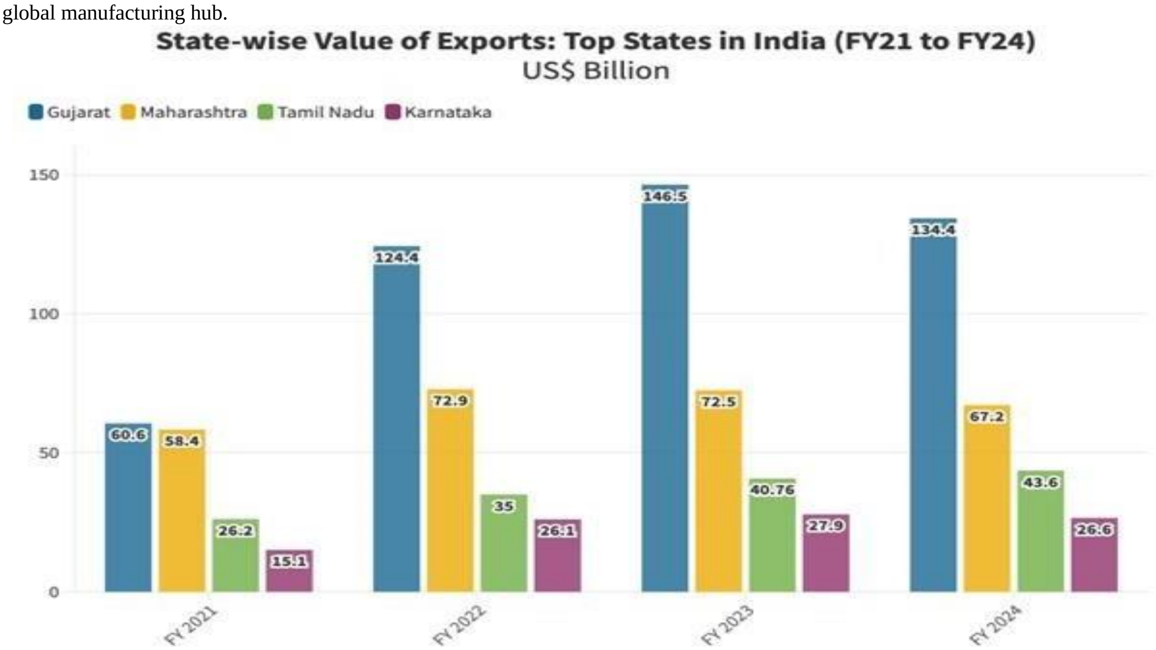
INTRODUCTION TO MANUFACTURING INDUSTRY

Manufacturing companies serve as the backbone of the global economy, significantly contributing to industrial growth, employment generation, and technological innovation. These companies specialize in converting raw materials into finished products that cater to various industries, including automotive, electronics, food processing, textiles, pharmaceuticals, chemicals, and heavy machinery. Their operations are integral to modern industrial frameworks, strengthening supply chains and fostering international trade.

Worldwide, manufacturing firms provide employment to millions of individuals across diverse skill levels. From engineers and factory workers to supply chain specialists and technicians, the sector supports a broad workforce. Manufacturing hubs often act as catalysts for economic expansion, stimulating infrastructure development and urban growth in the regions they operate. Nations such as China, Germany, the United States, and Japan have established themselves as global leaders in manufacturing, playing a vital role in their respective economies and shaping international trade patterns.

India's manufacturing sector is a vital pillar of the economy, driving industrial growth, employment, and exports. It spans multiple industries such as automotive, textiles, pharmaceuticals, electronics, and heavy machinery, playing a crucial role in economic expansion. The sector supports infrastructure development, enhances global trade competitiveness, and fosters technological advancements. To strengthen domestic production and attract foreign investment, the government has introduced initiatives like "Make in India" and Production Linked Incentive (PLI) schemes, aiming to reduce import dependence and boost industrial output.

Currently, the manufacturing industry contributes approximately 13% to India’s GDP, a decline from 17% in 2010. On a global scale, India holds around 2.9% of the total manufacturing output, generating an estimated $560 billion in 2023. Looking ahead, the sector is expected to witness significant growth, with projections indicating an increase from $355.79 billion in 2025 to $711.35 billion by 2034, achieving a compound annual growth rate (CAGR) of 8.2%. Strengthening the manufacturing ecosystem will be essential for increasing exports, fostering economic resilience, and positioning India as a leading global manufacturing hub.



Tamil Nadu is a key manufacturing hub in India, contributing significantly to industrial growth and exports. The state has a strong presence in **automobiles, electronics, textiles, heavy engineering, and renewable energy**. Chennai is a major automobile manufacturing centre, while Coimbatore and Tirupur lead in textiles and knitwear production. Hosur has gained importance in electronics and precision engineering. Tamil Nadu accounts for **14-15% of India’s total industrial output** and nearly **8% of the country’s manufacturing GDP**.

In 2023, the state's Gross State Domestic Product (GSDP) was about **$350 billion**, with manufacturing playing a crucial role. Government initiatives such as the **Tamil Nadu Industrial Policy 2021** are driving investment and industrial expansion. The state is also focusing on **electric vehicles, semiconductor production, and sustainable manufacturing**. With well-developed infrastructure, a skilled workforce, and foreign investments, Tamil Nadu continues to be a major force in India's manufacturing sector.

WIRE MANUFACTURING INDUSTRY

A wire manufacturing company specializes in producing various types of wires and cables essential for multiple industries, including electrical, telecommunications, construction, and automotive. These companies invest significantly in research and development (R&D) to enhance existing products and introduce new, innovative solutions. Advances in manufacturing technologies, such as 3D printing and material science, have enabled the creation of lighter, stronger, and more cost-effective materials, improving product efficiency.

Wire manufacturers must adhere to stringent industry regulations, particularly concerning safety and environmental standards. Continuous innovation in the sector has led to the development of more durable, flexible, and resistant wires capable of withstanding harsh environmental conditions such as heat and moisture. Many manufacturers also provide customized solutions, working closely with clients to develop specialized wires tailored to specific applications.

India's wire manufacturing industry is a vital contributor to multiple sectors, including electrical, telecommunications, construction, and automotive. It plays a key role in infrastructure development and power distribution by producing various types of wires and cables. Companies are adopting advanced technologies to enhance wire quality, durability, and energy efficiency. The industry is also shifting towards smart and eco-friendly wiring solutions to improve safety and performance. With infrastructure investments rising, the Indian wire and cable market is projected to grow at a **CAGR of 8-10%** in the coming years. The demand for high-speed internet networks and smart grids is further driving expansion. Continuous innovation and modernization are crucial for sustaining long-term growth in this sector. Strengthening domestic production will help India emerge as a major global player in wire manufacturing.

CRIMPING

Crimping is a method used to create a secure connection between a wire and a terminal by applying pressure or deforming them with a crimping tool or machine. This process ensures a reliable electrical connection and provides mechanical strength without the need for soldering or welding. It begins with stripping the insulation from the wire to expose the conductor, followed by inserting the wire into the terminal barrel. A crimping tool then applies pressure to secure the terminal onto the wire, forming two main types of crimps: a conductor crimp that ensures proper electrical conductivity and an insulation crimp that provides strain relief.

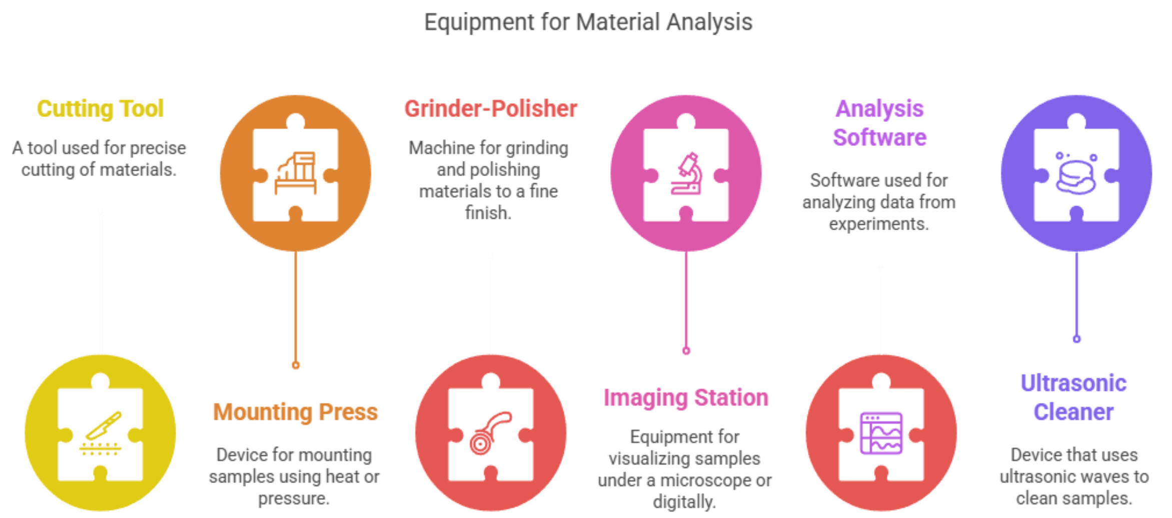
Different crimping methods are used depending on the application, including open barrel crimping (commonly used in automotive and industrial settings), closed barrel crimping (for high-reliability applications), hex crimping (for uniform compression), and indent crimping (for repairs). The quality of the crimped connection depends on key factors such as crimp height, width, pull-out force, conductor coverage, and insulation integrity. Over-crimping can damage the conductor and weaken the connection, while under-crimping can result in poor electrical contact. Quality control measures include pull tests to evaluate mechanical strength, micro-resistance tests to measure conductivity, and cross-section analysis to examine the internal structure for voids and deformation. Advanced crimping equipment, such as automated crimping machines and cross-section analysis tools, improves consistency and reduces defects. Crimping is essential in industries like automotive, aerospace, telecommunications, and medical equipment, where secure and low-resistance electrical connections are critical for performance and safety.

CRIMPING CROSS-SECTION ANALYSIS EQUIPMENT

Crimping cross-section analysis equipment includes specialized tools designed to evaluate the internal structure and quality of crimped wire connections. It ensures that crimped joints meet industry standards for electrical conductivity, mechanical strength, and long-term durability. The process involves cutting a crimped terminal at a right angle to the wire axis, polishing the cut surface, and examining it using a high-resolution microscope or imaging system. To enhance the contrast between the conductor, terminal, and insulation, the polished surface may be treated with an etching solution. The imaging system captures detailed visuals, which are then analyzed using specialized software to measure key parameters such as crimp height, width, conductor fill ratio, insulation grip, and strand alignment. This analysis helps identify common issues like over-crimping, under-crimping, voids, cracks, and misaligned conductors. Quality control methods such as pull tests, micro-resistance tests, and visual inspections are often combined with cross-section analysis to ensure consistency.

Modern crimping cross-section analysis equipment features automated sample handling, AI- driven analysis, cloud-based reporting, and 3D imaging, which enhance accuracy and operational efficiency. Industries such as automotive, aerospace, telecommunications, and medical devices rely on this equipment to ensure secure and low-resistance electrical connections for reliable performance. By providing a detailed view of the crimped connection's internal structure, cross-section analysis helps manufacturers identify and resolve defects, improve process consistency, reduce scrap rates, and enhance overall product quality.

MAIN COMPONENTS OF THE CRIMP CROSS-SECTION ANALYSIS EQUIPMENT



Crimp Cutting Device

Crimped terminals are cut using a fine diamond cutting hand saw blade. The terminal is clamped in a special holder, which ensures proper positioning and visibility. For larger components, machine-assisted cutting is used.

Grinding Machine

The cut crimp sample is ground using a specially designed grinding machine to prepare a smooth surface for analysis.

Crimped Surface Preparation & Projection

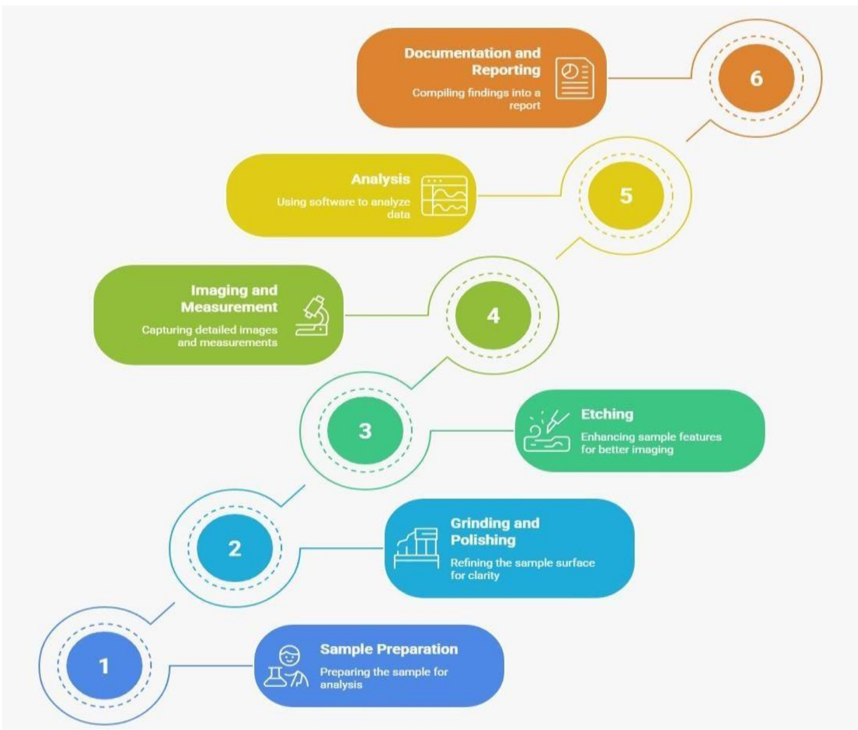
The prepared crimp, held in a dedicated fixture, is placed under a microscope. The image is captured by a camera and projected onto a computer screen. Focus and light

intensity are adjusted as needed. If the strands are not clearly visible, drops of etching solution are applied to the cut crimp until each strand becomes distinctly visible. A calibration system is in place to ensure measurement accuracy.

Software for Analysis

Specialized software supplied with the equipment provides precise measurements of crimp width, crimp height, and angles, and calculates the cross-sectional area of copper. Additionally, the software can detect voids and assess the uniformity of wing bending in the crimped area.

CRIMP CROSS-SECTION ANALYSIS EQUIPMENT – STEPS



1. ***Sample Preparation***

- **Cut the Crimp**: Use a precision cutter or saw to cut a crimped terminal perpendicular to the axis. The goal is a clean, flat surface.
- **Mounting**: Embed the cut section in a resin (cold or hot mounting) to stabilize and protect the sample.
- **Curing**: Allow the resin to cure fully. This may take several minutes (cold mounting) or less (hot mounting).

2. ***Grinding and Polishing***

- **Grinding**: Use grinding paper of progressively finer grit (e.g., P320 → P800 → P1200) to flatten and smooth the cross-section.
- **Polishing**: Use polishing cloths with diamond suspension (e.g., 6 µm, 3 µm, 1 µm) to get a mirror-like finish.
- **Cleaning**: Ultrasonically clean the sample to remove residue.

3. ***Etching (Optional, if needed)***

- Apply a chemical etchant to highlight grain boundaries or features. Not always required but can help visualize copper strands, terminal, and crimp contact.

4. ***Imaging and Measurement***

- **Insert into the Imaging Station**: Place the polished sample under a high-resolution microscope or metallographic imaging system.
- **Adjust Lighting and Focus**: Optimize light and magnification for clarity.
- **Capture Image**: Take a high-resolution image of the crimp cross-section.

5. ***Analysis (Using Software)***

- Use analysis software to:
  - Measure crimp height and width
  - Evaluate wire barrel compression
  - Count strands
  - Check symmetry
  - Identify voids, cracks, or missing strands
- Generate a report with dimensions and pass/fail criteria.

6. ***Documentation and Reporting***

- Save images and measurements
- Export or print quality inspection reports
- Store for traceability and quality assurance audits

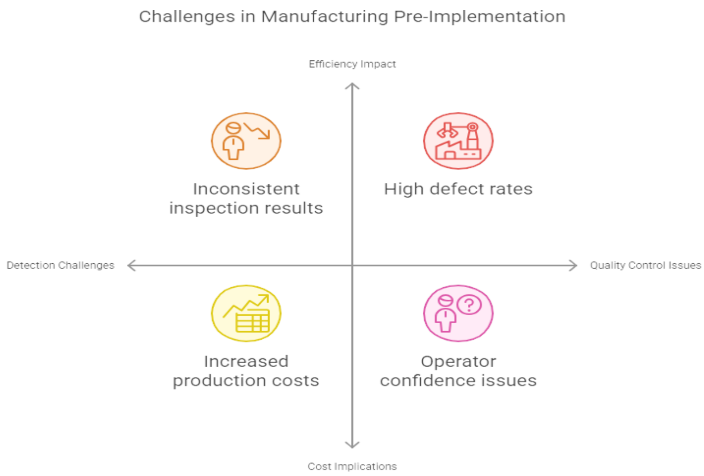
PRE-IMPLEMENTATION OFCRIMPING CROSS-SECTION ANALYSIS EQUIPMENT

Before the crimping cross-section analysis equipment was introduced, quality checks in the wire manufacturing process were carried out manually. These checks primarily involved visual inspection, basic pull tests, and simple measurements. Although commonly practiced, these methods were not capable of detecting hidden issues inside crimped terminals, such as loose wire compression, open barrel ends, or insulation damage. Due to the absence of tools for detailed cross-sectional or microscopic analysis, many defects were only discovered during the later stages of production or after the products had reached customers. This led to an increase in customer complaints and product failures. In 2021 and 2022, defect rates were significantly high, forcing the company to deal with increased rework and material wastage. Since the inspection process was manual, results often varied between operators, making it difficult to maintain consistent product quality.

Furthermore, the lack of proper documentation and traceability made it challenging to identify and correct the root causes of recurring problems. Without accurate tools to support their assessments, operators had lower confidence in their inspections, which negatively impacted the overall efficiency of the manufacturing process.

Challenges Faced Pre-implementation of Crimping Cross-Section Analysis Equipment

- Internal defects such as poor wire compression or insulation damage could not be detected through manual inspection.
- Crimping issues led to high defect rates and compromised product quality.
- Frequent rework and material scrap significantly increased production costs.
- Inspection results were inconsistent due to reliance on human judgment.
- Identifying the root causes of recurring defects was challenging.
- Operators lacked confidence in their manual inspection decisions.
- Overall process efficiency was reduced due to ineffective inspection methods.



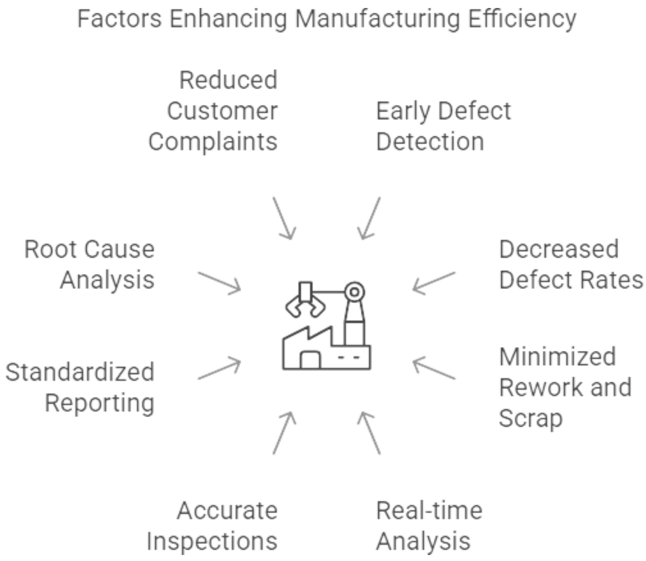
POST-IMPLEMENTATION OF CRIMPING CROSS-SECTION ANALYSIS EQUIPMENT

After the introduction of the crimping cross-section analysis equipment, the wire manufacturing process saw significant improvements in quality control and overall process efficiency. The new system enabled detailed inspection of crimped connections, allowing operators to view the internal structure of each crimp through microscopic cross-sectional imaging. This advanced capability made it possible to detect issues such as insufficient wire compression, incomplete barrel closure, voids, or insulation damage at much earlier stages. As a result, hidden defects that previously went unnoticed were now identified and addressed in real-time, reducing the likelihood of defective products reaching customers. By 2024, following the equipment's implementation, the company recorded a noticeable decrease in defect rates, rework efforts, and scrap generation. The equipment also standardized the inspection process by providing measurable and traceable data, eliminating inconsistencies common in manual assessments.

Furthermore, the system generated documented reports with images and precise measurements for each crimp, simplifying root cause analysis, audits, and long-term quality tracking. Operators felt more confident in their evaluations, as the tool offered objective evidence to support their assessments. Overall, the implementation of crimp cross-section analysis equipment not only enhanced product reliability but also significantly improved the efficiency and accountability of the entire manufacturing process.

Benefits

- Internal crimping defects like poor wire compression and insulation damage were detected early.
- Defect rates significantly decreased, improving overall product quality.
- Rework and scrap generation were minimized, reducing production costs.
- Real-time analysis allowed quick corrective actions during production.
- Inspection became more accurate, consistent, and reliable.
- Standardized reports and images improved traceability and documentation.
- Root cause analysis became easier with measurable data.
- Customer complaints decreased due to better product reliability.
- Overall manufacturing efficiency and quality control improved.



COMPANY PROFILE

Popular Systems Private Limited, established in 2005 and located in Coimbatore, Tamil Nadu, is a prominent manufacturer of high-quality wiring harnesses, junction boxes, control panels, and wiring accessories for various industries. The company focuses on delivering top-notch products at competitive prices, fostering customer trust through consistent quality and innovation. Its product offerings include customized wiring harness solutions for industries such as automotive, home appliances, medical equipment, and renewable energy. It also designs and manufactures custom-built junction boxes and control panels to meet specific client requirements across different applications. Additionally, the company supplies a broad range of wiring accessories that enhance the reliability and performance of electrical assemblies.

Popular Systems is certified under the Integrated Management System (IMS), holding certifications like IATF 16949:2016, ISO 9001:2015, ISO 14001:2015, and ISO 45001:2018,

demonstrating its commitment to maintaining high standards in quality, environmental management, and occupational health and safety. The company employs advanced technology and rigorous quality control measures to ensure the reliability and performance of its products. Its strong focus on excellence has positioned it as a reliable partner in industries that require secure and efficient electrical connections.

Established in the year	2005
Founder	K. Vijaya Prabhu
Nature of the company	Private Limited Company
Addition business	Manufacturing and supplying
Registered under	Registrar of Companies, Coimbatore, with Corporate Identification Number (CIN) U31900TZ2022PTC040567
Total man power	140
Website	https://www.popularsystems.net/
Address	D.No.6, Narayanaswamy Layout, Narasimhnaickenpalayam, Coimbatore, Tamil Nadu, 641031, India.

COMPANY CORE VALUES

At Popular Systems Private Limited, they provide high-quality wiring harnesses, junction boxes, control panels, and wiring accessories that meet industry standards and satisfy customer needs.

1 → Quality Excellence

2 → Innovation

3 → Customer Focus

4 → Integrity

5 → Teamwork

6 → Sustainability

7 → Accountability

OVERVIEW OF THE COMPANY

Popular Systems Private Limited began its operations in 2005, specializing in manufacturing and supplying high-quality wiring harnesses, junction boxes, control panels, and wiring accessories. The company is committed to delivering products that meet the highest industry standards, ensuring high performance, reliability, and customer satisfaction. All products are manufactured using high-quality raw materials sourced from reliable and trusted vendors.

Popular Systems maintains strict quality control measures at every stage of the manufacturing process, ensuring that all products comply with industry standards and guidelines. The company continuously monitors industry trends and technological advancements to enhance its product offerings and maintain a competitive edge.

With a strong focus on quality, innovation, and customer satisfaction, Popular Systems has built long-term relationships with clients across various industries. Its experienced team works diligently to design and manufacture products tailored to meet specific customer needs.
Through its commitment to excellence, Popular Systems has established itself as a trusted partner in industries requiring secure and efficient electrical connections.

COMPANY NAME: POPULAR SYSTEMS PRIVATE LIMITED

LOGO OF THE COMPANY

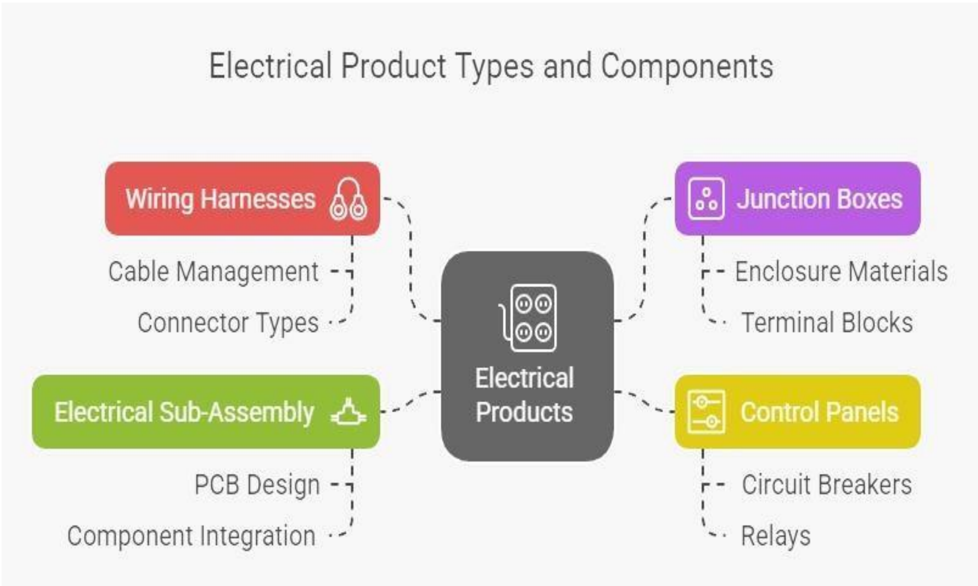
VISION

We are the committed team; creating healthy customer experience.

MISSION

Focuses on providing high-quality products at competitive prices to establish and maintain strong customer trust.

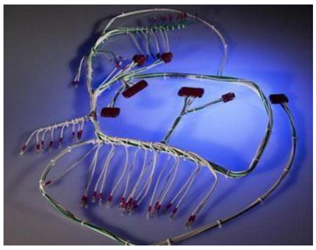
TYPES OF PRODUCTS



Wiring Harnesses

A wiring harness is a group of electrical wires, connectors, and terminals that help carry electrical signals and power within a system or machine. It makes the wiring process easier by combining multiple wires into one unit, reducing the chances of mistakes during installation. Protective coverings like sleeves and tubes are used to protect the wires from heat, moisture, and damage, ensuring they last longer. Connectors and terminals allow for secure attachment and easy removal, making maintenance simpler.

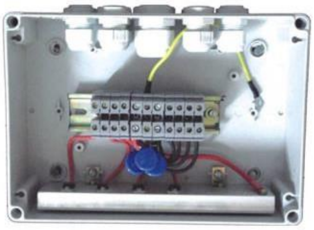
Wiring harnesses are used in many industries, including automotive, home appliances, medical equipment, and renewable energy. In cars, they connect parts like lights, sensors, and ignition systems to ensure smooth operation. In home appliances, the power motors and control panels, while in medical equipment, they support accurate signal transmission and power supply. In renewable energy, they help transfer power efficiently in solar panels and wind turbines. Wiring harnesses make installation easier, improve safety and reliability, and help organize electrical systems better.

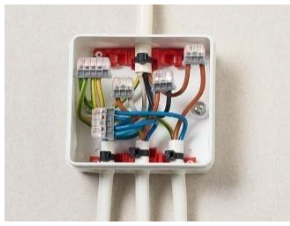


Junction Boxes

A junction box is a container used to protect and organize electrical connections. It holds the wires where different electrical circuits meet, making it easier to manage and distribute power safely. Junction boxes are usually made of plastic or metal and protect the wires from dust, moisture, and damage. They make the wiring process easier by providing a central place for connections, helping with easy installation and maintenance. Junction boxes often have openings for cables to enter and exit. Inside, the wires are connected using wire nuts or other connectors to keep them secure and organized.

Junction boxes are used in homes, offices, and factories. In homes, they connect lights, switches, and outlets. In factories, they help manage complex wiring systems and prevent electrical problems. Using a junction box improves safety, makes maintenance easier, and keeps the wiring organized.





Control Panels

A control panel is a system that contains electrical components such as switches, relays, circuit breakers, meters, and controllers used to operate and monitor machinery, equipment, and processes. It functions as the central hub where electrical signals and power are regulated to ensure smooth and safe operation. Control panels make it easier to manage complex systems by offering a single point for controlling different functions. They generally include switches to operate equipment, relays for automated switching, circuit breakers to protect against electrical overloads, and meters to measure values like voltage and current. Controllers adjust system settings and manage operations based on input signals. Control panels are widely used in industries like manufacturing, power distribution, HVAC systems, and renewable energy.

In manufacturing, they manage production lines and machinery, while in renewable energy, they regulate the output of solar panels and wind turbines. By improving efficiency, enhancing safety, and simplifying maintenance, control panels play a vital role in managing complex electrical systems.



Electrical Sub – Assembly

An electrical sub-assembly is a pre-assembled unit of electrical components such as wires, connectors, switches, relays, circuit breakers, and printed circuit boards (PCBs) designed to perform specific tasks within a larger system. It simplifies the creation of complex electrical systems by providing a ready-to-use module that handles power distribution, signal transmission, and control functions. Electrical sub-assemblies are widely used in industries like automotive, manufacturing, aerospace, medical, and renewable energy. In the automotive sector, they are used for managing engine control, lighting, and infotainment systems. In manufacturing, they help automate machinery and production lines, while in the medical sector, they enable accurate signal transmission and power supply for critical devices.

Electrical sub-assemblies enhance system reliability by minimizing wiring errors, improving safety with built-in protection, and simplifying maintenance through a modular design. Their ability to efficiently manage complex electrical functions makes them essential for improving the performance and reliability of modern systems.



PROBLEM STATEMENT

In wire manufacturing, the crimping process plays a vital role in ensuring strong and reliable electrical connections. However, inconsistencies in crimping can lead to quality defects, increased production costs, and material waste. To improve process reliability, crimping cross- section analysis equipment has been introduced, offering real-time, precise insights into crimp quality. This study seeks to examine the impact of this technology on manufacturing efficiency by analyzing key performance indicators before and after its implementation. The goal is to determine its effectiveness in enhancing quality control, reducing costs, and optimizing overall production processes through data-driven evaluation.

OBJECTIVES

- To compare the defect rates before and after the implementation of the equipment to assess improvements in quality control.
- To examine the reduction in rework costs as a reflection of enhanced process efficiency.
- To quantify the reduction in scrap rates before and after the implementation.

SCOPE OF THE STUDY

This research aims to analyze the impact of introducing crimping cross-section analysis equipment within the wire manufacturing sector. It primarily seeks to evaluate how this technology has affected overall process efficiency by reviewing key performance indicators, including defect rates, rework expenses, and material scrap levels. The analysis is based on data from two timeframes: prior to the equipment's adoption (2021 and 2022) and following its implementation (2024). The study also investigates enhancements in quality control and cost reduction achieved through more accurate crimp inspection and improved decision-making processes. Furthermore, feedback from machine operators has been gathered through a structured survey to assess the practicality and future potential of the equipment. The scope of the research is confined to one manufacturing facility, with a specific focus on its crimping operations. Ultimately, the results aim to provide valuable insights for similar industries looking to enhance efficiency and quality through automated solutions.

NEED FOR THE STUDY

In wire manufacturing, crimping is a vital process that directly affects the durability, reliability, and overall safety of electrical connections. Without precise quality inspection methods, defects may go unnoticed, leading to increased rework, excessive material waste, and possible product malfunctions. This research plays an important role in highlighting the practical advantages of using crimp cross-section analysis equipment, especially in reducing inconsistencies and improving process uniformity. As market expectations for flawless products and efficient production systems grow, the importance of adopting automated, data-centric quality control technologies becomes more evident. By evaluating key performance indicators before and after the equipment's integration, this study helps to assess improvements in efficiency, quality, and cost-effectiveness. Additionally, it serves as a decision-making tool for management when considering technological advancements and future process enhancements.

LIMITATIONS OF THE STUDY

Although this research offers valuable insights, it is not without limitations. The study is restricted to a single production unit, which may not adequately represent the range of crimping practices used across the wire manufacturing sector. The evaluation is based on historical data from select years—2021, 2022, and 2024—which may overlook long-term variations or external influences such as shifting market conditions, technological advancements, or workforce dynamics. Feedback collected from operators, while useful, is inherently subjective and may vary depending on individual skills and training. Furthermore, the focus is primarily on measurable performance metrics, with limited attention given to other influential factors like machine upkeep, material consistency, or human error. The analysis also presumes that no major operational changes took place during the study period, which could otherwise affect the reliability of the results. Additionally, the financial aspects, such as the cost of implementation and a comprehensive return on investment evaluation, are beyond the scope of this research.

CHAPTER II

REVIEW OF LITERATURE

A literature review is a comprehensive analysis and summary of existing research studies and scholarly works related to a specific topic or field. It involves critically examining and synthesizing the findings from prior research to identify trends, gaps, and inconsistencies in the existing body of knowledge. The primary aim of a literature review is to establish a strong theoretical foundation for new research, provide context for the study, and highlight the need for further investigation. By analyzing existing research, scholars can avoid repeating past mistakes, sharpen their research focus and questions, and gain a deeper understanding of the subject. A well-organized literature review compares various research methods, emphasizes key findings, and discusses the strengths and limitations of earlier studies. It also helps to identify unresolved issues and potential directions for future research. This process enables researchers to define the scope of their study, strengthen their arguments, and ensure that their research makes a meaningful contribution to the existing body of knowledge.

REVIEW ON CRIMP CROSS SECTION ANALYSIS EQUIPMENT

Ilca Dacian, et al. (2024), analyzed how different applicator tools affect the reliability of cable crimping in automotive manufacturing. Their study showed that while the Demirel applicator achieved the highest average pull strength, the Tyco applicator delivered the most consistent crimping performance across samples. The Schaefer applicator demonstrated good strength but had the highest variability. By testing 50 samples per tool and using pull tests and statistical analysis via Minitab, the researchers emphasized the importance of both strength and stability in crimp connections. The study concluded that selecting an applicator should depend on whether the priority is maximum strength or process consistency. Frequent calibration and tool selection optimization were deemed crucial for ensuring reliable production in high-stakes industries like automotive manufacturing.

Zhang et al. (2024), developed an analytical model to accurately predict crimping springback in large-diameter longitudinal welded pipes. Their model incorporates the effects of elastic modulus attenuation during plastic deformation and is based on Hill's bending theory. By integrating both analytical and numerical techniques, including a discrete plate element approach, the model improves prediction accuracy without excessive computational cost. Validation using real crimped pipe data showed a low error margin, with only 0.3° absolute error in springback angle. The study also investigated how material parameters like yield strength, hardening exponent, and elastic modulus influence springback. Results indicated that higher elastic modulus and yield strength increase post-springback bending angle, affecting dimensional accuracy. The chord modulus method used captures nonlinear unloading behavior effectively, enhancing realism in springback estimation. This model provides a reliable tool for optimizing pipe crimping processes in the oil and gas industry. The research offers significant industrial value by minimizing defects and ensuring weld alignment through better process planning.

Yan et al. (2024), proposed an innovative crimping and pultruding process using CF/PEEK prepreg tape for manufacturing space truss rods directly in orbit. This method addresses the challenges of continuous on-orbit construction by enabling efficient, lightweight, and high- performance rod formation. Numerical simulations and experimental tests were conducted to study how temperature and forming speed affect rod quality. Results revealed that forming load pull decreases with rising temperature and increases with forming speed, impacting surface smoothness, material density, and mechanical strength. The study introduced a novel rod curl pultrusion technique with in-rail, iso-material forming, supported by an optimized mold structure. Macroscopic mechanical properties of the unidirectional CF/PEEK material were considered during process validation. The technique demonstrated high efficiency, low energy use, and excellent integration for space applications. Optimal process parameters were determined for improved quality and reliability. This crimp-pultrusion method presents a promising solution for advanced, in-situ truss manufacturing in aerospace engineering.

Sheng et al. (2024), proposed the design of an intelligent fully automatic crimping device for grounding wires using a microcontroller-based control system and X-ray digital imaging technology. The device uses PID control to accurately manage the stepper motor's movement and hydraulic crimping force, achieving precise wire positioning and compression. The system enables automatic parameter setting via a control interface, with post-crimping quality verified through radiographic inspection. Experimental validation with 1000 samples showed a crimping success rate above 95%, with only 0.06mm average measurement deviation from actual values. Compared to two traditional crimping methods, this system demonstrated higher tensile strength stability, better measurement accuracy, and superior sensitivity. Its high reliability and consistent detection accuracy (~95%) suggest it is suitable for industrial-scale application in power transmission projects. The integration of automation and non-destructive testing improves operational efficiency while maintaining quality standards. The study demonstrates how intelligent automation can enhance construction quality in grounding wire applications.

Kim et al. (2023), explored the use of Magnetic Pulse Crimping (MPC) to enhance the quality and durability of crimped copper terminals, addressing common issues with traditional hand and hydraulic crimping methods. MPC utilizes high electromagnetic force, without physical contact, to uniformly compress wire strands and terminals, resulting in improved electrical performance and mechanical strength. The study analyzed the effects of two key process parameters—crimping length and charge energy—on compression quality. Findings showed that shorter crimping lengths improved the uniformity and effectiveness of the joint, while increased charge energy enhanced compression ratio and pullout strength. However, excessive charge energy caused damage to wire strands, highlighting the need for optimization. Numerical simulations of electromagnetic force distribution supported experimental results. Compared to conventional crimping, MPC significantly reduced defects like non-uniform pressure and wire separation. This non-contact method offers safer, more reliable connections for high-performance electrical applications. The study validates MPC as a viable, industrial- scale alternative to traditional crimping techniques.

Jongwuttanaruk et al. (2022), optimized the terminal crimping process using Response Surface Methodology (RSM) to enhance mechanical performance in automotive wire harnesses. Their study examined how crimp height, depth, and width influenced pull force, identifying an optimal configuration: 1.25mm height, 2.36mm depth, and 1.48mm width, achieving a maximum pull force of 13.60 Kgf. Using Minitab 18 and central composite design, the researchers showed that maintaining a compaction ratio between 15–20%, per SAE/USCAR-21 standards, improves crimp strength and reduces the risk of loose wire strands. ANOVA confirmed the model's reliability, and the study highlights the effectiveness of statistical modelling in achieving consistent, high-quality crimps in mass production.

Guo et al. (2022), designed an intelligent measuring device to improve the quality and efficiency of cable crimping in power transmission line construction. With the increasing scale of UHV transmission projects in China, the demand for accurate and reliable crimping measurement has grown. The proposed system is based on an STM32 microcontroller and integrates multiple digital sensors and measuring tools. This device replaces traditional manual measurement methods by digitizing and automating the crimping inspection process. It provides real-time data collection, processing, and storage, supporting faster quality checks and more consistent results. The system enables seamless data integration for construction and inspection teams, contributing to better project traceability. By adopting digital intelligence, the solution enhances both construction efficiency and crimping precision. The study supports the informatization of crimping practices in large-scale power infrastructure. The device lays the foundation for smart cable construction and inspection in the evolving energy industry.

Zhang et al. (2022), analyzed the crimping quality of overhead transmission line conductors using a new method based on equivalent cross-sectional stiffness. The study involved 26 specimen groups and identified five main failure modes, such as slip and wire breakage, influenced by parameters like pipe penetration depth and aluminium tube diameter. Load– displacement curves helped classify failure mechanisms, and simplified curve models were proposed. The results showed that mismatched crimping between the steel core and anchor or aluminium tube and conductor causes stress release, leading to failure. The authors emphasized the role of precise process parameters and stiffness analysis in improving grip strength and reducing failures in high-voltage transmission systems.

Kıvanç et al. (2022), proposed a novel crimping technique for high-power domestic appliance plugs, addressing issues of overheating, poor mechanical strength, and inconsistent performance in traditional methods. The new design was developed using an analytical methodology, supported by finite element method (FEM) simulations via COMSOL and Hyperworks. Experimental validation confirmed that the proposed crimp shape reduces temperature rise by 17% and improves breaking force by 8% compared to conventional designs. Simulations assessed electrical, thermal, and mechanical performance under 32A and 63A loads, demonstrating optimal force distribution and minimal plastic deformation. The design was optimized for both crimp height and crimp field ratio, ensuring stable electrical conductivity and structural integrity. Capability analysis showed high repeatability (6σ qualification with a process capability index of 5.72), confirming production readiness. Crimp prototypes underwent tensile and thermal testing under IEC and DIN standards, yielding reliable performance. The method offers improved durability, safety, and process efficiency in plug manufacturing. The study establishes a solid framework for modern crimp design in high- demand industrial applications.

Ilmi et al. (2022), conducted a comparative analysis of work efficiency in wire harness assembly at PT XYZ during the COVID-19 pandemic. The company experienced reduced productivity due to social distancing, prompting the need for process optimization. The study evaluated two scenarios: assembling head, body, and end components separately (Scenario 1), and a revised method combining body and end before final assembly (Scenario 2). Time studies revealed that Scenario 2 reduced total assembly time by 2756.38 seconds and improved productivity by 10%. The researchers used cycle time, normal time, and standard time calculations to measure efficiency, and fishbone diagrams to identify non-value-added activities. The greatest inefficiencies were found in the assembly stage, mainly due to improper equipment use and lack of SOPs. Scenario 2 minimized these inefficiencies by streamlining workflow and reducing operator wait times. The findings offer a practical solution for improving efficiency in labor-intensive industries under health restrictions.

Li et al. (2021), developed a mathematical model to analyze the relationship between indentation depth and tensile strength in aviation wiring harness crimping assemblies. By combining theoretical modelling with experimental data, they established how varying the indentation depth affects mechanical strength. Their results showed that an optimal range of indentation depth exists, where deformation is sufficient for strong bonding without over-compression that could lead to wire breakage. Using metallographic observations and tensile tests, they validated their model by comparing theoretical and experimental tensile strengths, which showed strong correlation within the optimal range. The study provided a precise geometric and elastoplastic analysis of the deformation and Springback behavior of crimped wires. A significant finding was that excessive crimping led to reduced tensile strength due to wire damage, while insufficient crimping led to easy disengagement. Their model allows for estimating ideal indentation depths without relying on repetitive destructive testing, improving efficiency in crimp tool design. The findings support predictive, standardized settings for future crimping operations, especially in aerospace. However, further studies were recommended to account for indenter shape variations and electrical performance metrics. This approach aids in designing more reliable, high-performance crimp connections.

Uzun et al. (2021), reviewed the methods and devices used to determine the quality of terminal crimping in electric cables, especially in high-speed, high-volume cable manufacturing. They outlined three main techniques—electrical testing, cross-sectional imaging, and force analysis—each with specific advantages and limitations. While electrical testing is fast and low-cost, it only measures performance and not causes of faults. Cross-sectional imaging provides detailed visual analysis but is time-consuming and requires skilled personnel. Force analysis, particularly with crimp force analyzers, offers real-time monitoring and fault detection during crimping. The study emphasized that combining these methods improves detection accuracy and ensures both electrical and mechanical reliability of crimped terminals.

Ștefan et al. (2021), explored strategies to optimize wiring harness assembly flows in the automotive industry through partial automation. As vehicles integrate more electronics, harness complexity and manual labor requirements rise, challenging productivity and consistency. The study examined current semi-automated processes like wire stripping, crimping, and sealing, and highlighted the low automation level in dynamic assembly lines. Using Witness Horizon simulation, researchers tested different hypotheses to resolve productivity bottlenecks, ultimately finding that redistributing tasks across workstations significantly reduced idle time and improved workflow. Advanced automated machines like the Zeta 640/650 and Omega 745/755 were introduced, showing promise in reducing manual workload and enhancing quality. Despite progress, the study noted full automation is constrained by wire flexibility, connector diversity, and changing customer requirements. Nevertheless, manufacturers that gradually adopt automation are positioned to gain a competitive edge through better cost efficiency and product quality. The research offers practical insights into scalable improvements for wire harness assembly systems.

Seo et al. (2019), investigated the impact of residual stresses induced in crimped metal shells used in hose assemblies, particularly focusing on tensile stresses in the circumferential direction. Their study emphasized that residual stress, often overlooked during design, can significantly degrade performance and lead to premature failure under service loads. Using both 1008 cold rolled steel and 5052 aluminium shells, they conducted impulse pressure tests and explicit finite element analysis (FEA) to simulate the crimping and subsequent pressure loading phases. The FEA results incorporated residual stresses from the crimping stage into the pressure test simulations. Findings revealed that residual stress substantially reduced the allowable stress range in the shell, leading to potential material yielding during dynamic loading. The analysis tracked full stress-strain histories, confirming the risk of plastic deformation. The study concluded that minimizing tensile residual stress is critical to enhancing durability and reliability in hose assemblies. Suggestions were provided to adjust the crimping process for improved stress distribution and structural integrity.

Weigelt et al. (2018), introduced a conceptual framework for integrating machine learning (ML) into ultrasonic crimping processes used in electric drive production. Recognizing the complexity and non-linearity of ultrasonic crimping, the study leverages ML to predict joint quality without relying heavily on physical simulation or domain-specific modelling. The proposed system uses visual features as input to train ML algorithms capable of assessing crimp quality in real time. This approach enables smarter process control, enhances automation, and supports rapid fault detection. The study outlines the system architecture and algorithm selection criteria, validating the concept with application-relevant use cases. The integration of ML offers flexibility in managing process variability and compensating for subtle material and operational differences. Challenges discussed include data quality, algorithm robustness, and implementation scalability. The paper sets the stage for future development of intelligent, self- adaptive manufacturing systems. It represents a forward-looking step in the evolution of smart crimping technology within Industry 4.0.

Castro et al. (2017), focused on optimizing a specialized tool for the crimping process of electrical terminals, addressing industrial demands for higher productivity and precision. The study was based on a real-world scenario where customer-specific requirements guided the design and development process. Emphasizing the role of engineering in tool development, the authors incorporated technical, functional, and operational criteria into the preliminary draft phase. The tool underwent optimization early in the design stage, with a detailed evaluation of materials, manufacturability, and cost. Attention was also given to tool operation and maintenance planning to ensure longevity and consistent performance. The final design aimed to fully leverage the capabilities of advanced crimping equipment. The tool was tailored for high-speed, high-accuracy terminal assembly in electrical systems. This case study demonstrates how early-stage design optimization and requirement-focused engineering can lead to robust, efficient tooling solutions. The study supports systematic tool development as a strategic factor in modern manufacturing.

Hou et al. (2015), proposed an automated system for crimp terminal section measurement using partial differential equation-based image segmentation. The system employs the C-V simplified segmentation model to automatically detect internal and external contours of crimp terminals from microscopic images. By integrating this model with MATLAB and .NET environments, the system measures parameters such as area, height, width, and deformation rate. The solution reduces manual labor, improves measurement accuracy, and standardizes report generation for harness quality control. The Level Set method used enables the system to perform well even in noisy or low-contrast images, making it robust for industrial use.

Experimental results showed accurate contour recognition under varying imaging conditions. The system architecture includes modules for image acquisition, processing, and analysis with automated output to Excel or Word. This development significantly enhances the efficiency and reliability of terminal inspection in automotive and electronics industries. The study supports broader adoption of intelligent vision systems in quality assurance processes.

Li et al. (2015), analyzed the crimping process of a turbo actuator in passenger vehicles using a multi-target orthogonal test method. The study aimed to optimize three key process parameters—surface bevel angle (β), upper die contour radius (R), and stamping pressure (P)— with respect to forming quality indicators E, F, and T, which reflect critical cross-sectional dimensions. Through orthogonal experimental design and range analysis, they identified surface bevel β as the most influential factor across all indicators. The optimal process combination found was $\beta = 8°$, $R = 6°$, and $P = 80$ KN. Further matrix analysis supported this combination as yielding the best quality and most stable dimensions. Validation was conducted through continuous production trials, where the proposed combination showed superior process capability and dimensional consistency. This result confirmed the practical application of orthogonal testing in mold design and quality control. The study offers a systematic, data- driven approach to improving crimping precision while reducing production waste and cost.

Yin et al. (2009), conducted a finite element analysis (FEA) to improve the crimping process quality of automotive electrical connectors. The study focused on optimizing terminal inner length and crimp height to achieve ideal "B"-shaped compression and meet compressibility standards. Using ABAQUS/Explicit, they simulated the 2D plane stress conditions of the crimping process, comparing FEA results with experimental data. Initial terminal designs, based on experience, failed to meet compressibility and resistance variation limits. The researchers proposed theoretical equations for calculating optimal inner length and crimp height, validated by simulations and physical tests. The modified design met the 80% compressibility requirement and significantly reduced resistance variation in thermal and humidity tests. Final results showed resistance changes were well within the 0.33 mΩ limit, confirming improved electrical performance. This method reduced the development cycle and improved product reliability. The study highlighted the critical role of numerical simulation in precision connector design for high-performance applications.

Abbas et al. (2002), conducted an advanced numerical simulation to analyze the crimping process of electric connectors using the finite element method. Their study compared implicit
and explicit solvers in ABAQUS, showing that explicit methods were more effective for handling complex contact conditions in the quasi-static crimping process. They found that using a 2D plane stress model better replicated real-world deformations, especially out-of- plane extrusion. Friction coefficients, strand positioning, and punch velocity significantly influenced crimp quality and simulation accuracy. The research demonstrated good alignment between simulated and experimental results, validating the models. These findings offer insights into improving crimp reliability and optimizing process parameters in electrical connector manufacturing.

CHAPTER III RESEARCH

METHODOLOGY

Research methodology is a crucial component that outlines the procedures, techniques, and
tools employed for collecting and analyzing data. For this study, the focus is on understanding the operational nuances and operator feedback regarding the use of automated crimping cross- section analysis equipment in wire crimping operations. The methodology adopted ensures that the data collected is relevant, accurate, and suitable for deriving meaningful conclusions about the equipment's effectiveness and operational impact.

RESEARCH DESIGN

This study adopts a **descriptive research design** to evaluate the impact of implementing automated crimping cross-section analysis equipment on process quality, defect reduction, and operational performance in a manufacturing environment. It compares key performance indicators such as **defect rates**, **rejection** & **rework costs and scrap percentage** before (2021–2022) and after (2023–2024) the integration of the automated analysis system.

The descriptive component highlights the transformation in quality assurance practices, production consistency, and operator performance following the equipment implementation. The comparative aspect quantitatively assesses the improvements over time by analyzing real- time data collected from production records and quality reports between the years 2021 and 2024.

Operator feedback was gathered through structured questionnaires to gain practical insights on challenges faced during operation, ease of using the new system, effectiveness in identifying defects, and suggestions for further optimization of the crimping processes.

Type of Research: Descriptive Research

Purpose: To analyze the effectiveness, challenges, and improvements associated with the implementation of automated crimping cross-section analysis equipment.

Method: Survey-based Analysis through Structured Questionnaires

Scope of Study: Focused on operators and employees directly involved in wire crimping and cross-section analysis activities.

PERIOD OF STUDY

The study was conducted over a period of two months, from December 16, 2024, to February 15, 2025. The data utilized for analysis was specifically extracted from the years 2021–2022 (before the implementation of the crimping cross-section analysis equipment), and 2023–2024 (After the implementation of the crimping cross-section analysis equipment). These years were purposefully selected to capture a comprehensive comparison of production quality, defect rates, rejection & rework costs, scrap percentage before and after the introduction of the automated crimping cross-section analysis system. A non-probability convenience sampling method was adopted for gathering feedback from operators. This approach facilitated easy access to first-hand insights regarding equipment performance, operational challenges, ease of use, and suggestions for further improvements in the crimping operations.

SOURCES OF DATA

The data collected for this study consists of both primary and secondary data.

- **Primary Data:** Primary data was obtained through structured questionnaires and surveys distributed to 25 operators directly interacting with the automated crimping cross-section analysis equipment. This data includes feedback, challenges, and observations regarding the system's impact on daily operations, such as improvements in process control, reduction in defects, and operator experiences with the new equipment.
- **Secondary Data:** Secondary data was gathered from company records, production reports, and historical data from the years 2021–2024 (before and after the equipment implementation). These data sources provided additional context and a broader understanding of the system's effects on operational efficiency, including metrics such as defect rates, rejection & rework costs, and scrap percentages.

SAMPLE SIZE

Quantitative Sample Size

For this study, the quantitative sample size was determined based on production and quality- related data collected across two distinct periods: before and after the implementation of the crimping cross-section analysis equipment. The focus was on evaluating key performance indicators, including defect rates, rejection & rework costs, and scrap percentages across a four- year span.

Pre-Implementation Window

The pre-implementation data was collected from **January 2021 to December 2022**. During this period, production processes relied heavily on manual inspection methods, leading to issues such as inconsistent quality analysis, undetected crimping defects, and increased rework & rejection costs. This phase served as the baseline for assessing operational challenges before introducing automated analysis technology.

Post-Implementation Window

The post-implementation data was collected from **January 2023 to December 2024**. During this period, the crimping cross-section analysis equipment was operational, enabling precise defect identification, improved quality consistency, and better process monitoring. The objective was to measure improvements in production efficiency, defect detection rates, and overall quality outcomes after automation.

Qualitative Sample Size

Responses were collected from **25 operators** through structured open-ended questionnaires. All participants were directly involved in wire crimping operations and the use of the crimping cross-section analysis equipment. This approach ensured that the feedback reflected practical, hands-on experiences with the system. The insights gathered focused on equipment usability, operational challenges, and opportunities for further improvement.

TOOLS USED

SPSS (Statistical Package for the Social Sciences)

SPSS was used for performing statistical analysis of the collected data. Specifically, the Paired t-test was conducted to compare the key parameters — such as defect rates, rejection & rework costs, and scrap percentages — before and after the implementation of the crimping cross- section analysis equipment. The Paired t-test helped in determining whether the observed improvements in process performance were statistically significant.

Microsoft Excel

Microsoft Excel was used to create graphical representations of the analyzed data. Various charts and graphs, such as bar graphs and line charts, were prepared to visualize trends in defect rates, rejection percentages, and operational costs over the four-year period (2021–2024). These visualizations made it easier to interpret the results and provided a clearer comparison between the pre- and post-implementation periods.

CHAPTER IV ANALYSIS AND INTERPRETATION

Analysis and interpretation are two important steps used to understand data or information. Analysis means breaking down complex data into smaller parts to identify patterns, trends, or relationships. It helps in organizing and examining the details carefully. Interpretation, on the other hand, involves explaining the meaning and importance of the analyzed data. It connects the findings to real-life situations or problems. Together, they help in drawing meaningful conclusions and making better decisions.

ANALYZING OPERATIONAL NUANCES IN WIRE CRIMPING

This objective is about understanding the details and challenges that affect how wire crimping works in everyday situations. This includes looking at things like how small changes in the process can impact the quality, efficiency, and performance of the crimping. The study focuses on areas like checking for quality issues, evaluating how well the process is running, and seeing how operator skills affect the results. It also involves analyzing the performance of the crimping machines to find areas that can be improved. By collecting feedback from operators, the goal is to find common problems and patterns that will help improve the crimping process and make it more efficient while ensuring higher quality results.

Operator's initial action when starting the equipment.

S. No	Response	No. of Operators
1	Verification of machine cleanliness	7
2	Verification of electricity connection	6
3	Verification of settings	7
4	Confirmation of machine functionality	5
	Total	**25**

INTERPRETATION

When starting the crimping cross-section analysis equipment, operators reported taking several initial actions to ensure proper operation. A majority began by verifying the cleanliness of the machine, ensuring that no contaminants could affect performance. Others confirmed that the electrical connection was properly established before proceeding. Another group focused on checking the machine settings to ensure accuracy and alignment with operational requirements.

Lastly, some operators confirmed whether the machine was functioning smoothly, indicating a check for any unusual sounds, delays, or irregular behavior. These actions reflect a systematic approach to equipment startup, emphasizing cleanliness, power readiness, configuration, and functional assessment.

Parts of the crimping cross-section analysis equipment that are difficult to operate.

S. No	Response	No. of Operators
1	Difficulty in setting the camera orientation	12
2	Difficulty in selecting the correct option from the menu	5
3	Confusion regarding the measurement part	5
4	Slow software performance	3
	Total	**25**

INTERPRETATION

The most frequently reported difficulty was in setting the camera orientation, indicating that aligning the camera correctly for capturing crimp images posed a challenge. Another reported issue was selecting the correct option from the software menu, suggesting that the interface may not be user-friendly or clearly labelled. Confusion regarding the measurement section reflected a lack of clarity in understanding or using that part of the system. Additionally, slow software performance was observed, which may hinder workflow efficiency. These findings point to usability concerns that could be addressed through interface simplification, better instructional support, and system optimization.

Step that takes the most time during crimping check.

S. No	Response	No. of Operators
1	Measurement verification	7
2	Defects inspection	5
3	Image focusing	6
4	Result recording	4
5	Calibration process	3
	Total	**25**

INTERPRETATION

Operators highlighted several steps that take the most time during the crimping check. Verification of measurements was identified as the most time-consuming task. Focusing the image and inspecting for defects also required considerable time. Additionally, recording the results and the calibration process were noted as time-intensive steps. These findings reflect the areas in the crimping check process where operators experience delays.

Common defects observed in the cross-section image.

S. No	Response	No. of Operators
1	Curved and distorted edges in crimp images	5
2	Division in the crimp image	6
3	Uneven wire strands	8
4	Incorrect cable insertion	3
5	Improper wire centering in the terminal	3
	Total	**25**

INTERPRETATION

Operators identified several common defects observed in the crimp cross-section images. The most frequently reported defect was uneven wire strands, suggesting alignment issues during the crimping process. Curved and distorted edges in the crimp images were also highlighted as significant concerns, indicating potential problems with the crimping die or material deformation. Division in the crimp image was another commonly noted defect, pointing to inconsistencies in the crimping process or material flow. Additionally, improper cable insertion and misalignment of the wire in the terminal were identified as factors negatively affecting crimping quality. These findings indicate key areas in the crimping process that may require further optimization to enhance consistency and overall quality.

Ease of understanding of the images and results (Yes/No).

S. No	Response	No. of Operators
1	No	13
2	Yes	12
	Total	**25**

INTERPRETATION

Regarding the ease of understanding the images and results, the majority of operators indicated that they found it challenging to comprehend the images and results. Conversely, 12 operators reported that the images and results were easy to understand. This feedback highlights a discrepancy in user experience, suggesting that further improvements could be made to enhance clarity and ease of interpretation for all operators.

Improvements to make the equipment faster or easier to use.

S. No	Response	No. of Operators
1	Quick pass/fail testing feature	7
2	Automatic measurement by the machine	6
3	Instructional videos	6
4	Machine fixing or setting things automatically	5
5	Simple software design for easy use	1
	Total	**25**

INTERPRETATION

Operators provided several suggestions for improvements to make the crimping cross-section analysis equipment faster and easier to use. A majority of operators recommended adding a quick pass/fail testing feature, which would simplify the process and save time. Another common suggestion was the implementation of automatic measurement by the machine, allowing for more autonomous operation. Instructional videos were also proposed to provide better guidance and support for operators. Some operators suggested that the machine should be capable of automatically fixing or setting things, which would reduce manual intervention. Finally, a simpler software design for easier use was mentioned, though it was noted by fewer operators. These suggestions reflect a desire for greater automation, efficiency, and user- friendliness in the equipment.

Suggested new feature for the equipment.

S. No	Response	No. of Operators
1	Cloud data storage and access	8
2	Automatic measurement and strand counting	6
3	Calibration reminder	4
4	AI defect detection	3
5	Autofocus camera	4
	Total	**25**

INTERPRETATION

Operators suggested several new features to enhance the equipment's functionality. The most commonly recommended feature was cloud data storage and access, which would facilitate easier management and retrieval of data. Another popular suggestion was automatic measurement and strand counting, aimed at reducing manual efforts and improving accuracy. A calibration reminder system was also proposed to ensure consistent machine performance. Additionally, some operators suggested the inclusion of AI-based defect detection to automate the identification of defects, while others recommended an autofocus camera for better image quality and precision. These suggestions highlight the need for increased automation, better data management, and improved precision in the crimping process.

Ongoing issues with the equipment.

S. No	Response	No. of Operators
1	Problems with centering and alignment	6
2	Software stops working	5
3	Measurements are unstable	5
4	Data storage issues	5

5	Images are sometimes unclear	4
	Total	**25**

INTERPRETATION

Operators identified several ongoing issues with the equipment. The most frequently reported problem was centering and alignment, which suggests challenges in achieving accurate positioning during the crimping process. Additionally, software malfunctions, where the system stops working, were also noted, indicating the potential need for software stability improvements. Unstable measurements were mentioned, suggesting inconsistencies in the measurement process that could affect the accuracy of the crimping results. There were also concerns about data storage issues, which could hinder the efficient saving and retrieval of important data. Lastly, unclear images were occasionally reported, highlighting a need for improvements in image clarity for accurate analysis. These issues reflect areas where the equipment could be further optimized to enhance its performance and reliability.

Skipping the equipment due to slowness or difficulty (Yes/No).

S. No	**Response**	**No. of Operators**
1	Yes	11
2	No	14
	Total	**25**

INTERPRETATION

Regarding the issue of skipping the equipment due to slowness or difficulty, 11 operators indicated that they sometimes skip using the equipment, suggesting that performance issues or operational difficulties may be hindering their workflow. In contrast, 14 operators reported no such issues and continue using the equipment without interruptions. This feedback reveals a split in user experience, highlighting that while some operators face challenges that affect their use of the equipment, others are not significantly impacted.

Need for additional training (Yes/No)

S. No	**Response**	**No. of Operators**
1	Use the software	9
2	Operate the machine	3
3	Measure correctly	3
4	Do's at each step	3
5	Not needed	7
	Total	25

INTERPRETATION

Regarding the need for additional training, a significant number of operators expressed the requirement for support in specific operational areas. The most commonly cited need was for training on how to use the software effectively, followed by the correct way to operate the machine. Some operators also indicated the need for better guidance on how to measure accurately and requested clear instructions on the do's at each step of the process. However, a portion of the operators stated that they did not require any additional training. This feedback highlights a mixed level of confidence among operators and suggests that focused training in key areas could enhance overall equipment usage and efficiency.

DEFECT RATE ANALYSIS

This objective is focused on evaluating the impact of new equipment on the quality of the wire crimping process. The goal is to measure the defect rates—the number of faulty or incorrect crimps—before the equipment was implemented and then compare them to the defect rates after the equipment was in use. By doing this, you aim to determine whether the new equipment has led to improvements in quality control by reducing defects. This comparison will help assess whether the equipment has made the process more efficient, reliable, and effective in producing higher-quality crimps.

Available Factor

Defect rate

Defect rate refers to the percentage or number of defective units identified in a production process compared to the total units produced. It is a key quality metric used to measure how frequently defects occur and is essential for evaluating the efficiency and reliability of manufacturing operations.

Paired Sample T – test

PAIRED SAMPLE T - TEST							
Pair	**Comparison**	**Paired Differences**			**t**	**df**	**Sig. (2-tailed)**
		Mean	**Std. Deviation**	**Std. Error Mean**			
Pair 1	Defect Rate 2021 - Defect Rate 2023	9.083	4.033	1.164	7.802	11	.000
Pair 2	Defect Rate 2022 - Defect Rate 2024	53.083	6.317	1.823	29.111	11	.000

INTERPRETATION

PAIR 1 – 2021 vs 2023 and PAIR 2 – 2022 vs 2024

The paired sample test results indicate a significant reduction in defect rates over the two observed periods. For Pair 1, the mean difference between defect rates in 2021 and 2023 is 9.083, with a t-value of 7.802 and a significance value (p-value) of 0.000, showing a statistically significant improvement. For Pair 2, the mean difference between defect rates in 2022 and 2024 is notably higher at 53.083, with a very strong t-value of 29.111 and the same highly significant p-value of 0.000. These results clearly demonstrate that the defect rates have significantly decreased in both cases, with the improvement from 2022 to 2024 being especially substantial.

DEFECT RATE TABLE

YEAR	**DEFECT RATE**
2021 – BEFORE	509
2022 – BEFORE	768
2023 – AFTER	400
2024 - AFTER	131

Table No: 4.1

DEFECT RATE CHART

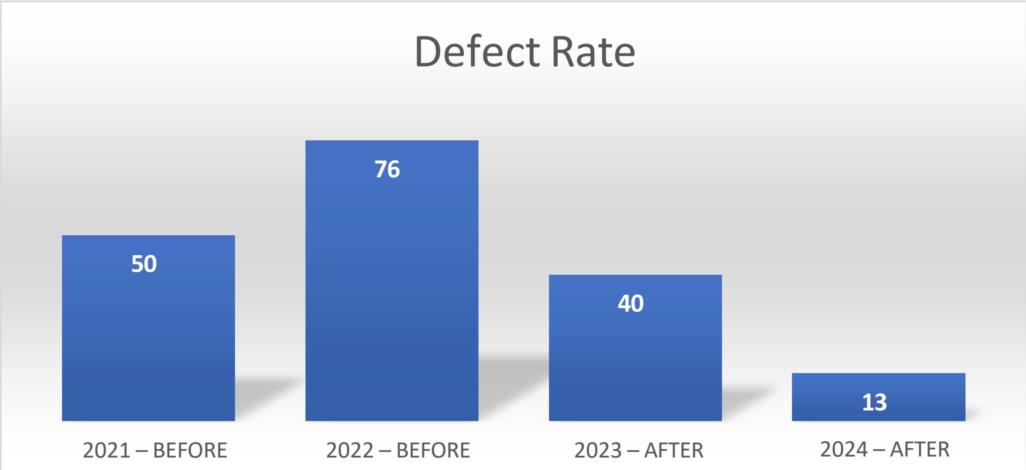


Chart No:4.1

REWORK AND REJECTION COST REDUCTION ANALYSIS

To examine the reduction in rework and rejection costs as an indicator of enhanced process efficiency.

Purpose

This objective is about looking at how much the costs related to fixing mistakes (rework) and discarding faulty products (rejection) have decreased. The goal is to see if these cost reductions show that the process has become more efficient. If the costs for rework and rejection are lower, it means the process is working better, with fewer errors and waste, which is a sign of improved efficiency.

Available Factor

Rework Cost

Rework cost refers to the total expenses incurred to correct defective or non-conforming products during the manufacturing process to bring them up to the required quality standards. These costs may include additional labor, replacement of materials or components, extra machine time, and subsequent quality inspections. Rework becomes necessary when products fail initial quality checks and must be repaired or modified before being deemed acceptable. While rework helps recover value from defective items, it increases production costs and may impact overall efficiency and customer satisfaction. Therefore, minimizing rework is crucial for maintaining operational excellence and reducing avoidable expenses.

Rejection Cost

Rejection cost encompasses all expenses associated with discarding products, components, or materials that fail to meet established quality standards and cannot be reworked or salvaged. These costs typically include the value of the wasted materials, labor and machine time spent on the rejected items, disposal or recycling fees, and any overhead allocated to handling and processing rejects. High rejection costs signal inefficiencies in production and quality control, as resources invested up to the point of rejection are lost. Reducing rejection costs is therefore vital for improving profitability, minimizing waste, and enhancing overall process reliability.

Paired Sample T – test

PAIRED SAMPLE T - TEST							
Pair	Comparison	Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Cost of Rejection 2021– Cost of Rejection 2023	462.000	218.161	62.978	7.336	11	.000

Pair 2	Cost of Rejection 2022 – Cost of Rejection 2024	1430.833	173.972	50.221	28.490	11	.000
Pair 3	Cost of Rework 2021 – Cost of Rework 2023	213.333	41.491	11.977	17.811	11	.000
Pair 4	Cost of Rework 2022 – Cost of Rework 2024	721.667	116.836	33.728	21.397	11	.000

INTERPRETATION

The paired sample test results show a statistically significant reduction in both rejection and rework costs over the years, as reflected in all four comparisons. The mean difference in rejection costs for the first and second pairs is ₹462 and ₹1,430.83 respectively, while the mean reduction in rework costs for the third and fourth pairs is ₹213.33 and ₹721.67. All tests have a significance value of .000, indicating that the reductions are highly significant and not due to chance. These findings suggest that the improvements implemented between the paired years— such as automation or enhanced inspection techniques—have effectively lowered both rejection and rework expenses, thereby improving cost efficiency in the process.

COST OF REJECTION AND REWORK TABLE

COST OF REJECTION	COST OF REWORK
13,994	6,810
20,580	10,340
8,450	4,250
3,410	1,680

Table No:4.2

COST OF REJECTION AND REWORK CHART

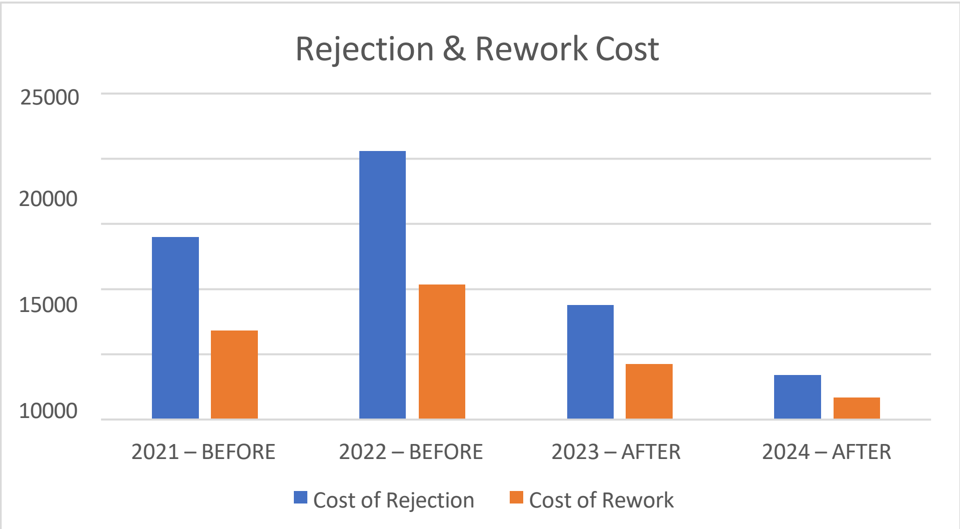


Chart No:4.2

SCRAP REDUCTION ANALYSIS

This objective refers to measuring how much the amount of waste (scrap) has decreased after the new system or equipment was introduced. This involves comparing the scrap percentage before the changes with the percentage after. The goal is to determine if the new system has led to less waste and more efficient use of materials in the production process. A reduction in scrap percentage not only indicates improved process control and product quality but also contributes to cost savings, reduced material consumption, and a more sustainable manufacturing approach. This evaluation helps in assessing the overall effectiveness and impact of the implementation on operational performance.

Available Factor

Scrap Percentage

Scrap Percentage is a metric used in manufacturing to represent the proportion of materials or products that are discarded as unusable or defective during the production process. It is usually expressed as a percentage of the total materials or units produced.

Formula

Scrap Percentage = (Scrap Quantity / Total Production Quantity) × 100

A high scrap percentage indicates inefficiencies or quality issues in the production process, while a low scrap percentage reflects better process control and material utilization.

PAIRED SAMPLE T - TEST

Pair	Comparison	Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1 2021 vs 2023	Scrap Percentage – Scrap Percentage	.47250	.03769	.01088	43.429	11	.000
Pair 2 2022 vs 2024	Scrap Percentage – Scrap Percentage	.90833	.04407	.01272	71.394	11	.000

INTERPRETATION

The paired sample test results indicate a significant decrease in scrap percentage between the compared years. For the 2021 vs 2023 pair, the mean reduction in scrap percentage is approximately 0.4725, while for the 2022 vs 2024 pair, the reduction is around 0.9083. Both comparisons show extremely high t-values (43.429 and 71.394) and p-values of .000, confirming that the differences are statistically significant. These results suggest that the measures implemented between the respective years—such as improved equipment or refined processes—were effective in minimizing scrap, leading to more efficient material usage and enhanced overall productivity.

SCRAP PERCENTAGE TABLE

YEAR	SCRAP PERCENTAGE
2021 – BEFORE	8.62
2022 – BEFORE	11.23
2023 – AFTER	2.95
2024 – AFTER	0.33

Table No: 4.3

SCRAP PERCENTAGE CHART

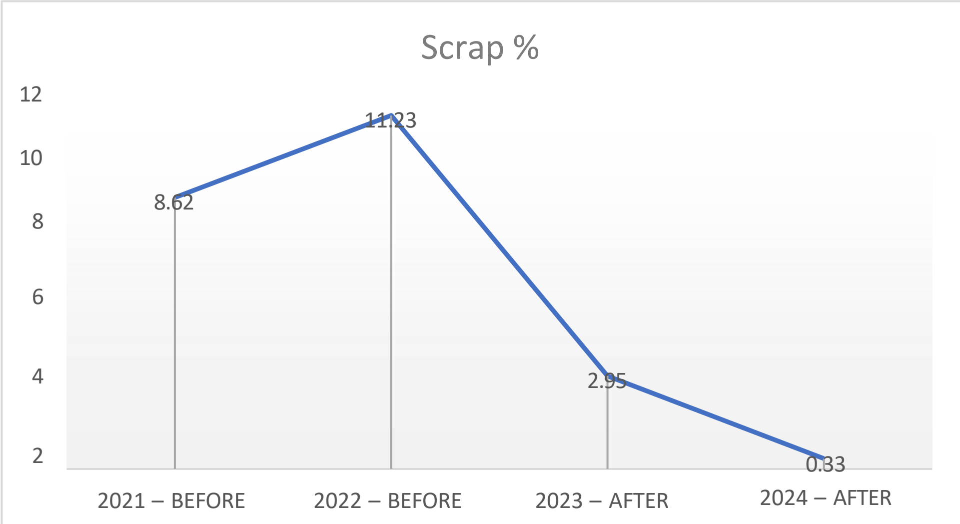


Chart No: 4.3

CHAPTER V

FINDINGS, SUGGESTIONS, CONCLUSION

FINDINGS

➢ **Operational Nuances in Wire Crimping**

Operators perform basic start-up checks but face difficulties with camera orientation, menu navigation, and accurate measurements. Verifying measurements and focusing images take the most time. Common defects include uneven wire strands, divisions, and distorted edges. Many operators find the results hard to understand and suggest adding automatic features and improving software usability. Persistent issues like alignment problems and software crashes remain, and most operators believe additional training would help.

➢ **Paired T-Test for Defect Rate**

The paired t-test for defect rate revealed a mean difference of 9.083 in one set and 53.083 in another, both with p-values of 0.000. These results indicate a statistically significant reduction in defect rate after the implementation of the crimping cross-section analysis equipment. This suggests that the equipment has contributed to improved process precision and product quality in wire crimping operations.

➢ **Paired T-Test for Cost of Rejection and Cost of Rework**

The paired t-test comparing cost of rejection and cost of rework showed a significant difference in the mean values, with a low p-value (typically $p < 0.05$) indicating statistical significance. This finding highlights a shift in the cost structure post-implementation, suggesting that while the cost of rework might have increased slightly due to more quality interventions, the cost of rejection has significantly decreased, reflecting better quality assurance and fewer defective products.

➢ **Paired T-Test for Scrap Percentage**

The paired t-test for scrap percentage showed a significant reduction in the average scrap rate, supported by a p-value below 0.05. This means that the introduction of the crimping cross- section analysis system has helped in minimizing material waste, thus enhancing material efficiency and cost-effectiveness in the production process.

SUGGESTIONS

- Implementation of an Auto Focus and Auto Alignment Camera to ensure consistently clear and properly aligned images for accurate crimp analysis.
- Integration of AI-Driven Defect Detection to automate the identification of defects, thereby improving speed and accuracy.

- Introduction of Auto Measurement and Strand Counting Software to automate measurements and strand counting, reducing human error and improving consistency.
- Incorporation of an Automated Calibration Reminder System to ensure timely recalibration and maintain measurement accuracy.
- Adoption of Cloud-Based Storage and Remote Access to centralize data, enabling remote access and collaboration across multiple locations.

CONCLUSION

The implementation of crimping cross-section analysis equipment at Popular Systems Pvt Ltd. has led to measurable improvements in process quality and operational efficiency. The statistical analysis of key indicators—defect rate, cost of rejection, cost of rework, and scrap percentage—before and after implementation confirmed significant reductions across all parameters. These findings were further supported by the results of paired sample t-tests, which validated the statistical significance of these improvements.

Operator feedback collected through a structured questionnaire also provided valuable insights. While many operators reported positive experiences with the equipment, particularly in terms of result clarity and performance reliability, some challenges were noted in areas such as machine usability, training needs, and processing speed. These responses highlight the importance of not only implementing advanced equipment but also ensuring it is user-friendly and supported by adequate operator training.

Overall, the project demonstrates that integrating analytical tools like cross-section analysis systems into the crimping process can enhance product quality, reduce waste, and lower operational costs. However, continuous improvement through automation, interface enhancement, and employee support will be essential for sustaining long-term benefits.

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